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Selected Topics Related to Infiltration and Inflow in Sewer Systems

American Public Works Association, Chicago, IL

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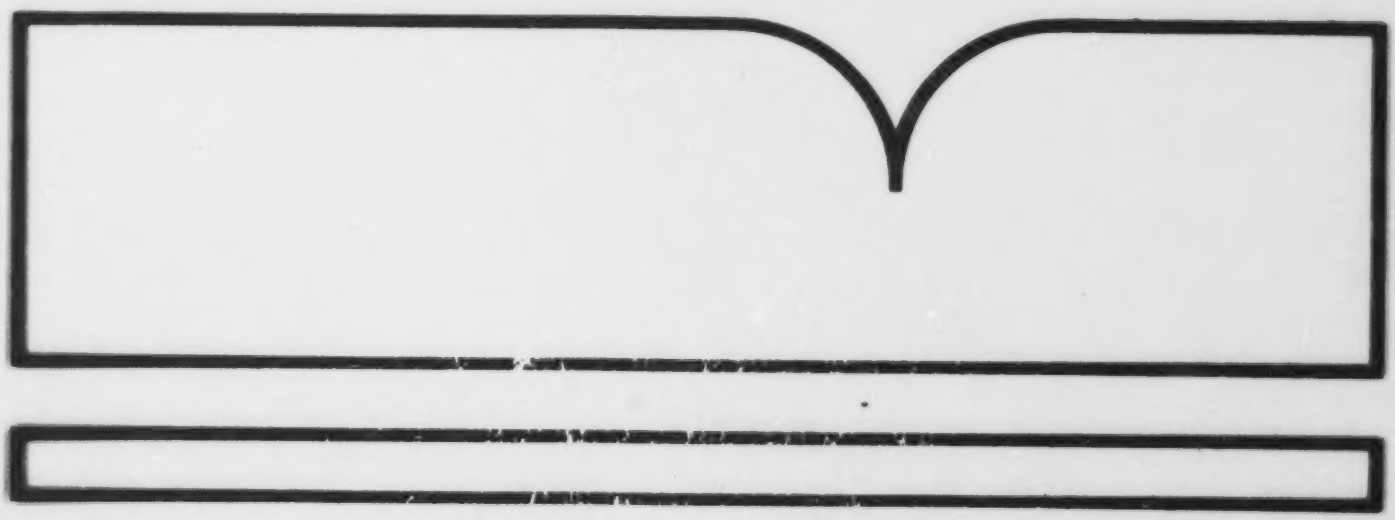

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Richard H. Sullivan
James W. Ewing II
American Public Works Association
Research Foundation
Chicago, Illinois 60637

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Project Officer

Carl A. Brunner
Wastewater Research Division
Water Engineering Research Laboratory
Cincinnati, Ohio 45268

WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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This project was undertaken as a review of the current state-of-the-art in infiltration/inflow control and to present information not included in earlier manuals and reports on this subject. A series of nine regional seminars was conducted to explore local problems and practices for solution. Chapters in this report respond to problem areas discussed at these seminars. Besides an overview, the report includes information on problem determination as approached by the Washington Suburban Sanitary Commission, methods for flow determination including a discussion of accuracy, economics of sewer rehabilitation, methods of rehabilitation, long-term rehabilitation programs, and long-term flow monitoring. A brief discussion is included of the major problems discussed at the regional seminars.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Control of Infiltration/Inflow has become a major early step in reducing the amount of untreated or poorly treated discharges of municipal sewage to receiving waters. This report has been prepared to provide information for those concerned with identifying and controlling Infiltration/Inflow.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

This project was undertaken as a review of the current state-of-the-art in infiltration/inflow control and to present information not included in earlier manuals and reports on this subject. A series of nine regional seminars was conducted to explore local problems and approaches for solution. Chapters in this report respond to problem areas discussed at these seminars. Besides an overview, the report includes information on problem determination as approached by the Washington Suburban Sanitary Commission, methods for flow determination including a discussion of accuracy, economics of sewer rehabilitation, methods of rehabilitation, long-term rehabilitation programs, and long-term flow monitoring. A brief discussion is included of the major problems discussed at the regional seminars.

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CHAPTER 1

OVERVIEW

The United States Environmental Protection Agency (USEPA), in the interest of providing timely information to public agencies, awarded a grant to the American Public Works Association (APWA) to review the state-of-the-art of Infiltration /Inflow (I/I) detection and control as well as sewer rehabilitation. Previous manuals prepared by the APWA and Conklin detailed the state-of-the-art as of the time of this preparation. However, in the years intervening, public agencies and consultants have developed a body of information concerning problems and practices associated with I/I control which have not been widely reported.

At the same time, the USEPA has acted to place the responsibility for conducting, implementing, and obtaining the results from I/I studies upon local public agencies. Thus, this report is aimed at providing local officials with developments since previous manuals were published.

A key concept inherent in this report is the need for local agencies to initiate an ongoing preventive maintenance program. This is necessary to maintain the minimum level of extraneous water flows. A sewer system cannot be rehabilitated on a one-time basis and be expected not to develop additional points of infiltration or inflow. One must keep in mind that multiple factors may be responsible for various types of defects which allow I/I to enter the system.

In using this report, it is essential to define the terms associated with I/I. For easy reference the terms are defined as follows:

"INFILTRATION" -- the volume of groundwater entering sewers and building sewer connections from the soil, through defective joints, broken or cracked pipe, improper connections, manhole walls, etc.

"INFLOW" -- the volume of any kind of water discharged into sewer lines from such sources as roof leaders, cellar and yard area drains, foundation drains, commercial and industrial "clean water" discharges, drains from springs and swampy areas, etc. It is distinguished from infiltration.

"INFILTRATION/INFLOW" (I/I) -- the volume of both infiltration water and inflow water found in existing sewer systems. Since the two sources of extraneous waters are practically indistinguishable, it is impossible to determine the amounts of either.

"SEWER SYSTEMS EVALUATION STUDY" (SSES) -- a process which follows the analysis stage and the recommendations based on the analysis process. The purpose is confirmation of overall findings gleaned from analyses of the program and conversion of preliminary diagnoses into firm conclusions as to the presence, location, and degree of I/I. SSES also determines what I/I intrusion is excessive in keeping conformity with criteria

stated in PL 92-500 and USEPA rules and regulations.

Over the past years, several manuals and reports have been written concerning I/I problems in sanitary sewer lines. This report does not replace earlier literature, but rather should be used in conjunction with the previous writings since it attempts to update the state-of-the-art and to introduce some newer techniques being used in the field, not only to rehabilitate the sewer systems, but also to evaluate systems and to certify the thoroughness of rehabilitation.

The report presents a review of the current state-of-the-art. Since only a review has been conducted, the major part of this report is intended for the practitioner with knowledge and experience of the subject area. To attain an overview of the national status of I/I detection, a series of nine regional seminars was conducted. Local experts and interested practitioners were invited to one-day sessions to explore local experience and practice. Participants discussed the solutions to problems they were experiencing. APWA then used those discussions as the starting point for the publication of the report.

At these regional meetings, APWA attempted to glean from participants what they considered to be their major regional problems, their best regional solutions and similar information on local I/I problems. Along with the regional problems, specific areas such as house laterals, illegal connections, groundwater migration, and similar problems were addressed. Although these problems have been discussed many times in the past, little research has been done in these areas nor has material been published on them.

The nine regional meetings highlighted the diversity of problems encountered by public agencies in various parts of the country. Because of physical conditions which exist, such as age of the system, local practices, soil and groundwater conditions it is apparent that national guidelines must be broad to allow for local needs.

In addition, the regional seminars provided an extensive review of the USEPA regulations governing I/I studies (CS-82). The review determined many potential trouble spots for local agencies in adhering to the guideline. Detailed comments were offered to USEPA.

Those who attended the seminars also identified two agencies which are conducting extensive local programs for I/I control: Washington Suburban Sanitary Commission (WSSC) of the City of Hyattsville, MD and the City of Salem, OR.

This report is based on comments made at the regional meetings. Chapters were developed to cover the major points discussed. For example, Chapter 2 describes the program of the Washington Suburban Sanitary Commission, a very comprehensive attempt to overcome many of the identifiable failings of the standard Sewer System Evaluation Study program. Under the program, internal inspection is scheduled to allow final rehabilitation recommendations by Autumn, 1985. The approach being followed is

designated as the "Systems Approach To Sewer System Evaluation." The "systems" approach in turn is based on the concept that collection systems have "individual personalities." Since certain system personalities behave similarly, personalities can generally be compared and defined where pipe type, joint material, and other accepted grantee compliance requirements are similar.

An accelerated pilot study of the "systems" approach to subarea rehabilitation has been approved by the local regulatory agency. The results of the study should be available at approximately the time the Sewer System Evaluation is completed.

Chapter 2 contains an analytical listing of the various methods, including smoke testing, used to determine if I/I should be considered excessive.

Chapter 3 describes the difficulties in determining precise flow in leaking house laterals. Such difficulties are the result of the inaccessibility of the point of discharge from the house lateral to the street sewer. The care to be taken to minimize the error inherent in each item of measurement is discussed in detail. In addition the chapter reviews interpretation of monitoring data and the potential range of error in discharge data. The chapter also reviews the range of error experienced in flow monitoring together with an error analysis scheme for estimating energy slope. The error in the parameters for various flow estimating formulae is also covered.

Chapter 4 reviews the economics of rehabilitation with the aim of aiding the investigator in making decisions by discussing the problems associated with current rehabilitation practices. One of the easiest of the rehabilitation techniques available on the market -- sealing and grouting -- is discussed. Associated problems arising from this technique, traffic control, mobilization, and cleaning are presented in detail. Similarly, the additional techniques are discussed with the view of what is needed to economically evaluate a rehabilitation project.

Chapter 5 is an evaluation of six basic techniques involved in rehabilitation processes for sewer mains. A decision tree outlining steps required for various methods of sewer rehabilitation is included. This chapter examines briefly these techniques and discusses the positive and negative aspects of the use of each. Processes reviewed are grouped under the following classifications:

1) Spot Repair
2) Reconstruction in Place
3) Construction of a Bypass
4) Grouting
5) Sliplining
6) Inversion Lining

The chapter also includes a flowchart which presents guidelines for the use of each technique.

Chapter 6 lists the materials and workmanship utilized in the inspection and maintenance processes of sewer systems. The inspection process discussed consists of two phases: cataloging through inventory and inspection by television surveillance. Also discussed are the two phases comprising the maintenance process: the repair of deteriorated sections and cleaning of the lines to allow free flow.

Chapter 7 separates the phases of long-term flow monitoring into three sections: preparation of location, purchase and installation of equipment, and evaluation of the project before and after completion. The chapter further discusses how the evaluation of the success or failure of a rehabilitation project should consider several factors: prior moisture conditions, flow vs. rainfall, flow vs. intensity, flow vs. duration, and existing conditions.

Chapter 8 summarizes comments of the participants at the various meetings held by APWA for the project. Topics summaried:

House Lateral Construction Problems
House Lateral Contributions
House Lateral Rehabilitation Techniques
Single Point Vs. Multi-Point Monitoring
Illegal Connections
Cross Connection
Manhole Inflow
Groundwater Migration
Cost Effective I/I Removal
New Development Standards
Improved Building Lateral Access

CHAPTER 2

THRESHOLD OF PROBLEM DETERMINATION

"Systems" Approach To Sewer System Evaluation Surveys and Rehabilitation

From its inception in the Clean Water Act in 1972, the Infiltration/Inflow (I/I) program has been developing. Studies conducted during its infancy produced unreasonable expectations of rehabilitation effectiveness and I/I reductions. Increasing awareness of the limitations of the original requirements have led to minor revisions in the format, i.e., PRM 78-10, permitting concurrent television and joint testing and sealing. In 1983 publishing of interim final Construction Grant rules followed in 1984 by final rules resulted in simplification of the approach dealing with I/I, and the imposing upon Construction Grant recipients of a requirement that effectiveness of control be certified.

Upon reviewing a number of completed Sewer System Evaluation Surveys (SSES), Conklin and others found that problems inherent in the surveys included: little recognition of the building sewer I/I contribution; inadequate flow measurements and assessments; unrealistic reduction expectations; imprecise cost-effective elements; impractical flow peaking factors; and minimal understanding of apparent ground water migration effects. Despite the problems, surveys have been continued, many in school book fashion, to satisfy I/I study requirements and to maintain other funding eligibilities.

In an effort to salvage what is perceived as a less than satisfactory situation, EPA has formally shifted responsibility for success to the grant recipient. The 1981 Clean Water Act amendments specify that I/I analyses and SSES work fall under the performance certification requirements which call for postrehabilitation compliance monitoring. The impact and interpretation of these requirements are still unclear. However, one fact is unmistakable; studies cannot be performed the same way they were done prior to the revised regulations. Modifications must be made to fulfill the certification requirements.

Many factors are involved for an agency to determine that a rate of I/I is excessive for their system. At present there are three methods for dealing with I/I.

The first is total removal of all I/I sources within the system, which in most cases will result in excessive costs. The second method is to define only those areas which contribute the major portion of I/I and limit cost effective repairs to those areas. The third method would be to disregard completely all I/I and simply transport and treat, at the wastewater treatment plant, all materials entering the sewer system.

In Construction Grant, 1982 Interim Final Report (CG-82), EPA suggests that a flow greater than 120 gal./capita/day (454 l/c/d) for the entire system would be that flow which EPA would consider to be cost effective in further evaluating the economics of removal of the major I/I sources. The 120 GPCD (454 l/c/d) figure used in CG-82 is based on an average sewage flow of 70 GPCD (265 l/c/d), and an average infiltration rate of 50 GPCD (189 l/c/d). The EPA flow rate is based on a single point measurement of the system at the entrance to the treatment plant and thus, reflects averaging of the overall system as to both infiltration and flow contribution of sanitary waste. One limitation of this technique is that it does not differentiate the intact areas of the sewer system which require no renovation and rehabilitation from the extremely poor areas which would benefit from rehabilitation.

The only way to accomplish such a differentiation would be to use the area monitoring system. Here, the entire sewage system is divided into subsystems. Subsystems are discrete contributing areas of the entire sewer system network and can be isolated and adequately monitored by placing monitoring devices in key manholes. The subsystem could be an entire drainage area or it could be nothing more than a subdrainage area of a larger drainage basin. The size of the area would not be as important as the fact that a flow measurement can be obtained for an area that has a reasonably consistent structural condition throughout.

Several years ago, the Washington Suburban Sanitary Commission (WSSC) recognized the shortcomings inherent in the standard method for SSES's and proposed a "systems" approach of study for the last significant SSES in the WSSC service area. A variety of departures from the established procedures were necessary to combat what they felt were existing deficiencies. The procedure followed included:

- Flow Monitoring
  - Subarea Long-Term Monitoring
  - Minisystem Temporary Monitoring
  - Subsystem Instantaneous Monitoring
- Physical Survey by Subarea
- Internal Inspection by Subsystem
- Cost-Effective Analysis by Subarea

FLOW MONITORING

Under current regulations the primary emphasis is for certification of the I/I reduction following sewerline rehabilitation. Most current studies cannot meet this requirement because of the limited amount of flow monitoring during the SSES. Any comparison of the system before and after rehabilitation would be apples and oranges and therefore not truly representative because of fluctuating water tables, differing precipitation activity, continued system deterioration, and many other factors.

Treatment plant monitoring has been emphasized, both in the past and presently, in the current compliance requirements. In many cases, this requirement is both impractical and imprudent. Like other large utilities, a part of the WSSC system discharges to pump stations of 0.1 to 105 MGD (0.3 - 397 MLD) capacity and is eventually conveyed to local and regional treatment plants of 1 to 300 MGD (3.7 to 1136 MLD) capacity. The rest of the system is collected by gravity to the plant with only few intermediate flow monitoring points in operation prior to 1981. Trunk sewer and treatment plant flow monitoring were found to be too gross a scale to be a valid indicator and recorder of I/I subarea problems.

Subarea Long-Term Monitoring

In the current SSES study by WSSC, long-term monitors have been established on 29 subareas within the 284 sq mi (456 sq km) of the study area. These subareas range in size from approximately 2.84 mi (4.5 km) to 16.1 mi (25.8 km) of sewer line. The range of collection system sizes stems partly from topographical subarea definition and from experimental pursuit of the ideal study size. Monitors are placed on the subarea outlet sewers prior to their junction with the interceptors. This permits more accurate monitoring and greater control of the flow calibrations than in trunk sewer metering.

The subarea monitors were in place a full eight months prior to subdividing the collection system into smaller minisystems, thus providing a more complete data base upon which excessive flow determinations could be made. This is the initial step in computing base flows for the postrehabilitation compliance requirement, a significant deviation from the "snapshot" approach to flow monitoring of earlier studies.

Such monitors are vital to the execution of the work after the initial determination of excessive I/I. Since they remain in place throughout the SSES and rehabilitation, these monitors provide a pulse for the system and give the earliest symptoms of significant changes in the subarea. Thus, they are ideal in checking the rehabilitation reductions and supplying a means of tracking system deterioration after the SSES. The WSSC subarea monitors will remain in place in those systems that do not have excessive I/I to serve as experimental controls. Ideally, after establishing the points of data collection, the monitors would be mobile from system to system for some extended period -- for instance, biannually, for use in an ongoing maintenance program.

Minisystem Temporary Monitoring

After a subarea has been found to have excessive I/I conditions, temporary monitoring of the minisystem is used to narrow the search for localized defects.

Depending on topographic constraints, these minisystems have averaged between 3,000 and 6,000 ft (914 - 1829 m) in size. When deployed in a minisystem, the long-term subarea outlet meter provides a checks and balances control against which the sum total of the temporary monitors

can be evaluated. The meters were used for 21 days during the highest ground water historical month. Since an extended data base exists at the subarea long-term monitor, ground water activity can be reviewed as well as the infiltration levels recorded at these sites to provide further indications of optimal deployment timeframes.

Subsystem Instantaneous Metering

In the traditional SSES, instantaneous measurements took the form of selectively dissecting a minisystem into line sections and performing night isolation and measurement on each. Line sections exceeding a minimum flow value were recommended for internal inspection. This process has led to limited focus of the problem and fragmented the field work to the point where it invites migration effects. Migration occurs when groundwater which is excluded from a sewer by repair at one point flows outside the pipe to an unrepaired location and enters the sewer at the new location. From all indications, migration will be a factor in adjacent line sections but will not transfer from one minisystem to another, i.e., hydraulic gradients governing the ground water flow will not be shifted dramatically enough to make system transfer possible. Any analysis to combat migration must then be made at this subsystem stage of the survey.

To try to prevent this migration phenomenon, subsystem instantaneous measurements for WSSC took the form of outlet and junctions (O&Js), so designated because they are typically performed at outlet and junction manholes within the minisystem. The working parameter has been approximately 1,000 ft (305 m) of sewer, 4 average line sections, measured per O&J. This subsystem block, when evaluated for I/I excessiveness is the basis for the internal inspection recommendation. By inspecting and evaluating the subsystem blocks rather than unrelated, fragmented, individual line sections, the impact of adjacent, but nonleaking, defects can better be evaluated to preclude migration in any rehabilitation recommendations.

PHYSICAL SURVEY

Under this system, manhole inspection and visual lamping are pursued for all subareas considered excessive infiltration/inflow. The subarea size was selected for this activity for several reasons. Manhole inspection is an extremely efficient way to evaluate the visible and accessible part of the collection system. Cost-efficiencies permit this activity to be done on a larger scale than other evaluation techniques. It also has been shown that manhole grouting for infiltration reduction and manhole frame sealing for inflow elimination are two of the most cost-effective corrections that can be made.

Rainfall simulation, smoke testing and selective dyed water flooding are utilized in the traditional sense. Improved testing techniques are employed, but the approach is essentially unchanged. Building inspections may be employed when other activities do not fully account for the level of inflow measured.

INTERNAL INSPECTION

The only significant change used by WSSC to internal inspection is that subsystem blocks, rather than isolated line sections, are inspected during the high ground water period. All defects are inventoried and evaluated for their impact on effects of migration. Leaking and nonleaking defects will carry similar weight when reviewing these areas for rehabilitation.

COST-EFFECTIVE ANALYSIS

Of all the components of the SSES, this step is the most abstract and, therefore, perhaps the hardest to properly assess. The cost-effective analysis (CEA) combines treatment plant costs, collection system transport costs and relief/replacement sewer options, to form a present worth analysis. The CEA is then computed for specific point source repairs taking into account the infiltration quantity at the source and a percentage of effectiveness of the repair. This tunnel vision system of correcting only significantly leaking defects found during an internal inspection on one day of one year may result only in perpetuating the failure of I/I programs.

All rehabilitation determinations in the innovative SSES by WSSC will be made with respect to the subarea meter. The subarea meter is the focal point for the amount of infiltration to be used in the subarea CEA. The subarea meter becomes the control for evaluating flows and making rehabilitation recommendations. The subarea meter also becomes the means of postrehabilitation compliance certification.

Reviews of past I/I studies contain overly optimistic estimates of flow reduction. Apparently, past estimates for I/I reduction have been made on the basis of 60-100 percent reductions in the areas which are being repaired. The investigation would pinpoint areas of severe infiltration and a project would be implemented to correct these problems. No thought was given to the phenomenon of migration and its effect on adjacent sections. As a result, large leaks were plugged and small leaks ignored. Migration of ground water allowed the infiltration to enter through the small leaks. The net result was a very small decrease in overall I/I. These same reviews indicate that a more realistic assessment might be in the 30 percent reduction range.

Keeping this in mind, the proposed CEA will utilize a 30 percent reduction as a target factor for use in the cost-effective equation.

Infiltration will be measured at the subarea meter. Treatment, transport, and relief components will be factored into the analysis and then the overall effectiveness of the rehabilitation program will be projected.

The results were used to reveal the estimated amount of money which could be cost-effectively spent to make the system corrections necessary for a 30 percent reduction in the excessive infiltration and inflow.

If the expenditure needed to correct those defects in the subarea to effect a 30 percent infiltration reduction is less than the amount computed, then repairs can begin.

Judgment is a factor in applying this procedure. The progression (thread) of flow measurements from subarea metering to minisystem temporary monitoring to subsystem outlet and junctions provides the flow measurements necessary to form a judgment. Internal inspection of subsystem blocks rather than isolated line sections provides the inventory of leaking and nonleaking defects needed to properly assess the rehabilitation potential to help preclude migration.

This concept has immense potential. In past studies at WSSC, it's been found that collection systems have individual "personalities." Certain system personalities behave in similar ways. Personalities can generally be defined where pipe type, joint material, and other accepted grantee compliance requirements are similar.

Test and seal pilot studies in the WSSC service area found, for instance, that standard strength vitrified clay with jute and mortar/GK compound joints built before 1945 had an extremely high air test failure rate. When these collection systems are encountered, air testing is eliminated and sealing proceeds on each joint of the affected line section. By extrapolating such system responses and evaluations to all the components involved (pipe, construction practices, types of connection, building sewer material, joint material, age, location in system, topography, infiltration rates existing and potential, manhole construction, etc.), it is possible to make a judgment on the CEA. These judgments must be used wisely as the subarea monitoring also serves as the postrehabilitation flow reduction compliance check. Greater flexibility in the CEA must be tempered with the responsibility to effect verifiable reductions required of the grantee.

SUMMARY

The WSSC is involved in one of the most comprehensive attempts to overcome many of the identified shortfalls of the standard SSES program. Subarea monitoring began in the Spring, 1982. Minisystem and subsystem flow activities were completed in the Spring of 1983. Inflow identification was completed during the Summer and Fall, 1983. Internal inspection will proceed during Spring, 1984 with the final rehabilitation recommendations due in Fall, 1985.

An accelerated pilot study of the "systems" approach to subarea rehabilitation has been approved by the local regulatory agency. Several subareas will be selected from the SSES study area and rehabilitation will be implemented on the subarea basis. Results are due at approximately the time of completion for the rest of the SSES.

This innovative "systems" approach to executing the SSES is not the last step. Already, improvements and modifications have been suggested. Perhaps the most valuable aspect of the systems "approach" is in suggesting an alternative procedure which meets the grantee compliance aspects required in current legislation and which provides the flexibility to achieve the desired reductions.

MIGRATION

Service laterals typically contribute a good deal of both infiltration and inflow to a sanitary sewer system. A service lateral source may be located in the connection of the lateral to the sewer main and along the lateral's pipe barrel and joints. Service laterals also transport virtually all of the inflow that originates in the private sector.

Overview

The determination of the rate of infiltration from service laterals is generally done in the same way as for sources in the sewer main by using visual measurement based on internal inspection. The determination of inflow rates is more direct using internal inspection together with dye-water flooding with flow measurements at the downstream manhole. The inflow measured for the segment is assigned only to sources that result in a positive test. Interpretation of data from the internal inspection of service laterals is more difficult than from other sources because it is often not obvious whether the source is located at the sewer main connection or whether it originates along the service lateral pipeline.

The uncertainty regarding the location of the infiltration or inflow source in a service lateral, combined with the inherent cost of excavation, have made repairs to service laterals generally less cost-effective than rehabilitation of other sources. Even when rehabilitation is successful at the source, migration to other defects in the sewer main and laterals has resulted in limited overall flow reduction. Findings from a recent migration study seem to indicate that more effective rehabilitation of service laterals can be achieved.

Migration from rehabilitated sources was recently studied in detail for two typical residential sites in a combined effort by the Washington Suburban Sanitary Commission and RJN Environmental Associates, Inc. Segment by segment infiltration was measured by plugging and weiring. Ground water was monitored from observation wells installed for the study. Each site contained approximately twelve segments and twenty wells. Data was collected semiweekly for four months.

The rehabilitation results obtained during the monitoring period indicate that localized "mounding" of ground water in the sewer trench occurring at rehabilitated points can increase but can be partially relieved by unrehabilitated sources. If there are none nearby, then ground water relief is achieved by dissipation to the surrounding soil.

Service lateral sources tend to be at a higher point than sources impacting only the main. Migration trends, therefore, cause an infiltrating sewer main defect to flow more due to the increase in hydrostatic head. Where there is a significant rise in ground water level, a normally dry service lateral may begin to contribute I/I after local rehabilitation occurs. As a result, after rehabilitation has been performed nearby, the possibility of a service lateral contributing I/I cannot be ruled out simply because it was inactive during the internal inspection prior to rehabilitation of the main.

Migration may be reduced and rehabilitation effectiveness increased if the unrehabilitated sources are not near those being rehabilitated, and if the permeability level of the surrounding soil is reasonably near to the permeability level of the trench. If this is not the case, "mounded" ground water will more easily travel in the trench and migrate farther to unrehabilitated sources, as opposed to seeking relief through immediate dissipation in the surrounding soil.

The potential for infiltration from seemingly "dry" service laterals should be determined based on the condition of the connection and other considerations, such as jointing, pipe materials, methods of construction, or how similar laterals in the area that are known to be at or below the water table behave.

SINGLE POINT VS. KEY MANHOLE MONITORING

In general, economics will dictate when single point or key manhole monitoring should be used.

Single Point Monitoring.

Single point flow monitoring defines the hydraulic characteristics of a collection system utilizing flow data obtained from a single point, usually a pump station or treatment facility at the downstream end of the system. Single point flow monitoring is relatively inexpensive and has been accepted by the USEPA for preliminary evaluation as to whether the tributary system has excessive I/I.

If single point monitoring determines that flow is less than 120 GPCD (454 lpcd), the system, by USEPA definition, does not have excessive I/I and no further study is necessary. If I/I is found to be excessive, additional evidence is required to show that it is still more expensive to transport and treat it than remedy the I/I. If this can be shown, then the I/I may be eligible for USEPA grant money to remove it.

Single point flow monitoring has been used effectively in relatively small (less than 100,000 linear feet (30,480 m) collection systems. In these systems, where I/I is found to be "excessive," it is generally more economical to smoke test the entire system and complete the related follow-up SSES tasks than to break the system into a series of subsystems by flow monitoring.

The smoke is valuable since it is reasonably inexpensive and easy to use. The crew to be trained in the operation requires only a technician level supervisor to obtain credible results in a short period of time.

Key Manhole Monitoring.

Key manhole monitoring breaks the collection system into a series of definable subsystems. There is some controversy as to length of pipe within each subsystem to maximize the effects of this type of monitoring which will be discussed later. The advantages are:

1) Flow monitoring may help to eliminate some of the subsystems from further study.

2) This type of flow monitoring can set priorities for the subsystems relative to I/I severity.

3) More data is available to identify hydraulic restrictions.

4) Flow monitoring, if performed regularly, can build a foundation for a data base which can be used in the future to evaluate the sewer system as the population increases and the sewers become older.

5) SSES completion time may be reduced by eliminating subareas from further study.

6) Better correlation of flow, e.g., leaks found vs. monitored flow may be obtained.

7) The reaction of each subsystem to the entire system for a particular storm can be identified; this reaction is particularly important when rainfall varies in intensity across the collection system or monitoring area.

8) Peak wet-weather flows are less travel-time dependent, making the hydrograph easier to interpolate.

9) A more effective maintenance program can be implemented; the program places emphasis on the subsystems, where most of the I/I originates.

Some of the disadvantages to key manhole monitoring are:

1) Multipoint monitoring is initially more expensive.

2) Resources required to monitor and maintain flow monitors increase in direct proportion to the number of monitors used.

3) Some difficulty can be expected in balancing flows where one subsystem flows through another, due to travel time, monitor accuracy, and varying rainfall patterns.

4) Eliminating some subsystems from further study overlooks I/I point sources in these subsystems that could be eliminated cost-effectively.

5) Unexpected surcharging of sewers makes flow depth data useless. Anticipated surcharging can be handled by the use of appropriate equipment.

Although initially much more expensive than single point flow monitoring, in most cases key manhole monitoring will be the most economical approach because time will not have been wasted looking for leaks which do not exist during a rehabilitation project.

MONITOR SPACING.

There is considerable controversy about appropriate spacing for multiple monitoring locations. One school recommends intensive real-time monitoring, claiming that only through detailed, time-dependent comparison of data from adjacent monitors can field conditions be correctly interpreted. In addition, when surcharging occurs, two adjacent depth monitors can be used to establish the difference in water level between the sewer inverts at monitoring manholes. The head loss can be used to calculate flow, using a pipe full formula. The justification for intensive monitoring is that savings in cost of cleaning and TV inspection in those reaches found to have low I/I more than offset monitoring costs. The problem is that I/I usually occurs throughout in varying intensities. One monitoring station for each 10,000 to 20,000 linear feet (3048 - 6096 m) of main and lateral sewers (excluding service connections) is reasonable for the preliminary survey, but the final survey should allow about 4,000 feet (1219 m) per monitoring station.

INTENSIFIED SMOKE TESTING

Like most I/I identification and correction procedures, smoke testing of sanitary sewers is more complex than originally anticipated. Weather and ground water conditions are only two of the factors which affect the results obtained from a smoke testing program. In addition, smoke testing procedures and the results obtained from it have been found to vary with the number of blowers, blower spacing, and blower air output. These items can have significant impact on the identification of ground

water infiltration and stormwater sources in a sanitary sewer system.

Smoke testing of sanitary sewers has been used as a relatively quick and inexpensive way to locate inflow sources in a sanitary sewer system. Smoke is generally blown into the sanitary sewer by a specially designed gasoline-powered blower. Smoke for the test is generated by either a fuse lit smoke "bomb" or a smoke canister. Since smoke testing procedures have generally not been standardized, field procedures have been developed over the years.

Smoke testing is a reliable method of identifying "direct" inflow sources such as downspouts, area drains, driveway drains, loading dock drains, and direct cross-connections between the storm sewers and the sanitary sewer. Such inflow sources generally have a direct path to the sanitary sewer. Ideal field procedures and weather conditions are usually not required to detect these sources.

The ability of smoke testing to identify "indirect" I/I, sources such as foundation drains, service lateral defects, and indirect storm sewer to sanitary sewer cross-connections, is not as well documented. These I/I sources do not always have a "direct" path from the surface to the sanitary sewer so the smoke must pass through seams in the soil to reach the surface before it can be detected.

Controlled Field Tests

A section of the City of Des Plaines, IL sanitary sewer system known to contain several I/I sources was smoke tested by RJN Environmental Associates, Inc. to evaluate various smoke test procedures. The test section consisted of nine manholes and approximately 2,100 linear feet (640 m) of sanitary sewer. All tests were conducted on the same day in October 1981, when the ground water table was low and the ground surface was dry. Because the tests were conducted on the same day and also for the same sewer lines, results could be attributed to each of the field procedures that was evaluated, including:

1) Number of smoke blowers
2) Spacing of smoke blowers
3) Blower air output

Five different test procedures were evaluated, as shown in Table 1, SMOKE TEST PROCEDURES EVALUATED. Upstream and downstream lines were sandbagged and five minute smoke bombs were used during all tests. Test One involved a single smoke blower set up on the center manhole of two adjacent sewer line reaches. Smoke was blown both upstream and downstream from the center manhole with the blower running at full throttle. Test Two also involved the use of a single blower running at full throttle, but only one sanitary sewer line reach was tested at a time with the smoke blown towards the downstream manhole. Test Three used two blowers with the blowers set up at the upstream and downstream manholes of two adjacent sewer line reaches. Smoke was blown upstream and downstream towards the center manhole with blowers at full throttle. Test Four used the same set up, but both blowers were set at approximately half throttle for this test. Test Five was performed with

the blowers set at full throttle on each manhole so that each individual sewer segment had smoke blown simultaneously from the upstream and the downstream manholes.

The location and intensity of smoke reaching the surface was recorded on field forms for all tests. Results showed that the number of I/I sources identified depends on the field procedure. Test procedure No. 5 identified most I/I sources and resulted in the most intense smoke reaching the ground surface, as shown in Table 2,.

I/I sources with a direct flow path to the sanitary sewer, such as stairway drains, driveway drains, roof leaders, and area drains, were generally identified in all the tests, although Test No. 1 and Test No. 4 failed to detect one source each. Both of these tests were made with smoke blowers set up on every other manhole.

I/I sources which have no direct flow path to the sanitary sewer include direct cross-connections with storm sewers, foundation drains, and defective building service laterals. Smoke must generally pass through soil seams to reach the surface and be detected. Test results showed that the number of "indirect" I/I sources varied significantly from one testing technique to another. Best results were obtained when only one sewer line segment was tested at a time and when both blowers were run at full throttle. Almost as good results were obtained with one blower wher it was run full throttle with the smoke being directed in only one direction.

Conclusions

Close attention to field procedures is important when conducting a smoke testing program. Each sewer line segment should be tested with a smoke blower at both the upstream and the downstream manholes. Blowers should be run at full throttle, if the intention is to identify I/I sources other than "direct" inflow sources, such as roof leaders, driveway drains, stairway drains or directly connected storm sewer inlets.

Table 1

SMOKE TEST PROCEDURES EVALUATED

Test	Number of Smoke Blowers	Smoke Blower Spacing	Smoke Blower Throttling
1	1	Every Other Manhole	Full Throttle
2	1	Every Manhole	Full Throttle
3	2	Every Other Manhole	Full Throttle
4	2	Every Other Manhole	Half Throttle
5	2	Every Manhole	Full Throttle

TABLE 2

INFILTRATION/INFLOW SOURCES IDENTIFIED

"Direct" I/I Sources

Test	Stairway Drains	Driveway Drains	Roof Leaders	Area Drains
1	5	1	1	1
2	5	1	1	2
3	5	1	1	2
4	4	1	1	2
5	5	1	1	2

"Indirect" I/I Sources

Test	Storm Sewer Inlets	Foundation Drains	Defective Service Laterals	Total I/I Sources Identified
1	3	13	3	27
2	4	21	8	42
3	4	17	8	38
4	4	10	7	29
5	4	22	8	43

ILLEGAL CONNECTIONS TO HOUSE LATERALS

All sanitary sewers are subject to infiltration and inflow. But if the research done by Seattle, Washington and WSSC is representative of the prevailing conditions of house laterals, inflow from these may be the greatest source of extraneous water entering the system. In the individual house lateral (infiltration is not the same problem as is encountered in main or trunk sewers) the length and diameter of the pipe is much smaller and the lateral is generally above the main pipe and often above the normal ground water level.

In older sections of an urban area, roof leaders, floor drains, foundation drains, etc. often were connected to the sanitary sewer which may have started as a combined sewer. When separate storm drains were installed in the streets, these flow sources remained and were not transferred to the new storm drains because of the high costs involved in the relocation. Some cities were aware of this and condoned the retention of these connections. Small lots and dense urban development left little area for surface disposal of roof water. Dry wells had limited life due to the accumulation of solids entering them from roof leaders. As to floor and foundation drains; storm drains, when existing, were usually above basement elevations.

Originally, inflow in the sanitary system may not have been a problem, since the older pipe design methods employ several safety factors which provide excess initial flow capacities. High estimates of per capita flows, a 25 percent reserve capacity for expansion, and the philosophy of "make it big, costs are not critical," generally resulted in overdesigned systems capable of accommodating some inflow. Treatment plants, if in existence, were usually primary treatment only, and the increased hydraulic loadings due to the temporary influence of inflow only moved through the plant faster. In addition, to keep the cost of service to the consumer at a minimum, the calculated costs of treatment in these early plants were artificially low.

Inflow from house laterals is not limited to older sections of a sewered area. Newer developments have, and will continue to have, illegal connections. Builders and developers are interested in getting rid of the water as quickly and inexpensively as possible. If adequate stormwater drainage facilities are not provided, such flows are very apt to enter the sanitary sewer system.

Usually, when a building develops a water problem, sometimes years after it is built, underdrains and/or sump pumps are installed and routinely connected to the sanitary sewer. Another longstanding practice is to install a cleanout in the sanitary sewer line with its top flush with the basement floor. The homeowner experiencing water in the basement opens the cleanout plug and flushes the water into the sanitary sewer.

Monitoring flows in the system can indicate the type of inflow being experienced. A sudden rise of flow at the treatment plant and in interceptors during and shortly after a heavy rain which peaks and recedes rapidly, can indicate surface inflow components. The source may be from roof drains, yard drains, catch basins, and open direct sources such as cleanouts. After a long period of rainy weather, usually in the spring or fall, a slow increase in peak I/I may be observed. This peak lasting sometimes for a long period of time and receding relatively slowly, usually indicates ground water entering the system through foundation drains, floor drains, and leaking service laterals.

Inspection and detection of illegal connections is very difficult and time consuming. For many years it was the standard to install a trap at the point just outside of the building to eliminate the intrusion of gas and odors. Then what is now considered an illegal drain--the footing drain--was connected on the building side of the trap. Presently a contractor or

homeowner who wants to make an illegal connection may install a trap in the line to reduce the possibility of detection.

Those installing sumps and/or underdrains in existing buildings may not secure permits. Builders on new construction or major renovation will have the sewer line inspected and approved and may then tie in a drainage tile. The use of ball valves or back flow preventors is common and recommended for many locations such as overloaded sewers, flat grades, low topography, etc. But the use of traps and back flow preventors can retard or make smoke testing ineffective, which is the most common, quickest, and least costly method of checking for illegal connections.

The solution lies in education, inspection, surveillance, enforcement, and legal commitment. Education is the heart of the program. The homeowner may eliminate the illegal connection on his own, if convinced that it is in his best interest. Citizens need to be informed that illegal connections add many gallons of water to the sanitary system which can cause the system to fail or discharge polluted water to the streams, streets, and ground. An overloaded system may in turn need to be enlarged; new sewer mains, pump stations, and treatment plants may be required to convey the additional flows. In most cases, the stormwater could be discharged to receiving waters without treatment. The cost of treatment for clean water and polluted water in a wastewater treatment plant is the same. Newspapers, radio reports, public information meetings, and information pamphlets distributed by service clubs or attached to utility bills, can be effective educational tools.

As the program is prepared, the municipality must decide who will pay for the removal of documented illegal connections. At this point the cooperation of the property owners is very important. If the City assumes the cost of disconnection, much of the potential hostility of property owners can be avoided. Some of the cost could be assumed by the City, such as the cost of disconnection, while any costs for reconnection to storm drains, dry wells, or streams could be assumed by the property owners. Or, as an alternative, the total cost could be assumed by the City with refunding to the City by the owner over a specified time period as is done with sewer assessments.

The preceding ideas are in operation in various parts of the country. The City of Dallas, TX requires the property owner to assume all responsibility toward reduction of inflow from his lateral. If the property owner is stubborn, the city terminates water service until the owner has repaired his service. Salem, OR has a scale for which property owners are surcharged depending on the type of inflow problem they have. Joint assumption of responsibility is practiced in Oregon too.

Inspection covers identifying the areas of greatest and least inflow and then setting priorities and programs to reduce or eliminate the I/I. Flow measurements of sewer lines in dry and wet weather can identify the areas of highest concern. Televising sewer mains will provide visual comparisons of laterals discharging at higher rates than normal sanitary

flow. House-to-house inspections can be made where smoke testing has been found to be ineffective, but where flow measurements, visual inspection of sewer mains, and flow calculations indicate excessive inflow exists. An inspection of a basement and its exposed plumbing may show that illegal connections are present. An inspection of the outside of the building may reveal whether yard drains are present and roof leaders are piped into the ground. If a yard drain has no apparent discharge to a storm drain or surface outlet, it can be suspected of being connected to the sanitary sewer. Proceeding with the investigation, the property owner or occupant should be interviewed to obtain any additional information regarding the illegal connections. Each suspected unit must be checked. The best way to do this is to introduce water and a bright colored dye (special dyes are made for this purpose) into the unit and then check the appearance of the immediate downstream manhole or cleanout.

This is a long process as sufficient time must elapse between tests to remove all traces of the dye from previous tests. However, it provides positive identification if carefully performed. Testing of roof leaders and drains suspected of being in a dry well can sometimes be confirmed by using a smoke test through the inlet. If the dry well is not deep and the ground not hard packed, smoke will be released through the ground. During the removal process, sewer lateral cleanouts should be secured tightly and raised as much as possible above the basement floor.

Once illegal sewer connections have been removed, steps must be taken to prevent their recurrence. Builders and owners should certify in writing that no illegal connections are present in new construction or major remodeling. The property owners should periodically be reminded of the negative effects of illegal connections.

The surveillance part of the Program requires a continuing effort. Periodic checks of flow in local sewers should be made, sudden changes in flows at treatment plant and pump stations noted, and random spot checks of buildings in a suspected area instituted. Inspectors of new construction or renovation should make sure that all sewer trenches are backfilled immediately after inspection, that individual plumbing permits for sanitary piping in buildings are checked, that a final inspection is made of subfloor piping just prior to the concrete floor being poured, and that new house laterals replacing old subsurface disposal systems are checked for their full length and backfilled before any illegal taps can be made.

Enforcement and legal commitment are the least desirable parts of the program but are perhaps the most important. An ordinance should be drawn specifically making the installation and/or continued use of a connection to the sanitary sewer of any wastewater other than sanitary, a civil violation punishable by fine and the fine should be great enough to act as a deterrent. The amount should vary with the higher fines being assessed against a builder or contractor who makes an illegal connection in new construction or major renovations, while the lower fines are assessed against an owner who goes along with the contractor's suggestion to make the connections. A method of collection should be set without resorting to the already overcrowded court system. A reduction of a

property owner's sewer use fee if he has proven that no illegal connections exist and if he continues to maintain that status, might also serve as an incentive.

As was discussed earlier, Oregon uses a surcharge for discovered but not corrected inflow presently in operation. Once the property owner has corrected the problem, and the city has inspected and approved the repairs, the surcharge is eliminated from the bill.

Inflow and infiltration studies have shown that more then 50 percent of the extraneous sewer water is inflow which comes primarily from service laterals. The detection of this inflow is time consuming, but the removal can be imaginative, and the results rewarding in terms of a task accomplished and tax dollars saved.

CHAPTER 3

FLOW DETERMINATION

METHODS

Several methods to measure flow in a sewer line are commonly used. Probably the most common is the measurement of depth of flow in a length of pipe and calculation of flow rate with a relationship such as the Manning Equation. The next level of complexity involves insertion of a weir or a flume with measurement of water level upstream of the flow restricting device. All of these require a method for measuring liquid levels accurately. The most commonly used, at present, appears to be the dipper monitor and its close competitor, the bubbler. With the advent of solid-state technology, several others have come into use recently: (the electronic level detector and the electronic velocity-level detector.) Still another is dye dilution, a technique which uses only a laboratory and sampling technique.

DIRECT MEASUREMENT OF FLOW DEPTH

The direct measurement method, in its simplest terms, is the placement of some kind of measuring device, that is, 6 ft rule (1.8 m) yardstick or some similarly marked stick, into the flow as close to the invert of the pipe as one can estimate. The observer then reads the flow level on the rule as closely as he can. Normally, this falls within 0.10 ft (3.05 cm) to 0.05 ft (1.52 cm) of actual flow depth. This is generally how calibration checks are made on electronic and mechanical measuring equipment.

THE DIPPER MONITOR

The next simplest method is the use of a dipper or float. A known channel cross section with calculated flow characteristics is inserted into the sewer line at an accessible location. Generally, a Parschall flume is used. This device allows a direct correlation between depth and quantity of flow since the flow cross section is rectangular. The Parshall flume utilizes a float which is connected through a series of levers or gears to a pen. The pen in turn marks either a strip chart or a circle chart. After reading the marks on the chart, a technician can convert those into a calculated flow through the flume over the period of time measured on the chart.

Several problems are involved in this method, however: one being that because of the nature of the discharge the dipper is measuring, foreign material can cling to the float causing inaccuracies due to the float's reaction to changes in flow depths, and therefore, flow volumes. Second,

should the sewer line surcharge, and the float reach its point of maximum travel, the flow could exceed the calibrated limits of the Parshall flume. In this case, only a rough estimate of the total flow can be surmised from the chart by extrapolating the intersection point of the ascending and descending legs. Besides, Parshall flumes are calibrated for certain flow ranges. A small Parshall flume is accurate for very small flows, but overflows the benches rapidly. A large Parshall flume, on the other hand, while having a greater range of flows than it can measure, can not differentiate between small variations in those flows. Although the Parshall flume, theoretically, is directly converting depth of flow to quantity of flow, there are times when it will be impossible to obtain accurate flow data from the depth of flow. The Parshall flume measures depth of flow only; it cannot measure velocity through it.

A variation of the flow monitor utilizing a float involves a level sensor. This device has an electrically operated probe with two electrical contacts at the end. The probe is lowered until the electrical contacts enter the flow, which completes an electrical circuit. The closed circuit results in the sensor being withdrawn a short distance and the elevation of the sensor head recorded at that point. After a predetermined interval, the process is repeated.

Fouling of the head, resulting in either a continuous electric current or no current at all, can cause problems using this technique. It does however offer an advantage in that the sensor and its associated strip charts are reasonably inexpensive to purchase and maintain.

Most of the problems associated with fouling of the recording instrument are present in any kind of recording device utilizing mechanical reading of either depth of flow or velocity of flow, such as dippers, floats, propeller-meters, etc.

THE BUBBLER

The next step up in technology is the bubbler. This device also uses a known cross section for measuring the flow, commonly using a Parshall flume. In place of an instrument which measures the top level of the flow, however, it has a small airway tube which exits at the bottom of the Parshall flume. A low volume, low pressure pump pressurizes the airway until the pressure in the airway is marginally greater than the pressure exerted at the bottom of the flume and a bubble is formed. Hence the name, bubbler.

Because pressure at the bottom of the flow is directly proportional to the depth of flow, the air pressure needed to cause a bubble can be directly equated to the depth of flow. The more pressure needed to create the bubble, the greater the depth of flow. The pressure required to force a bubble can be indicated on a strip chart or a circle chart. In much the same way that the float movement is charted, a barometric measuring device will record variations in air pressure levels on a strip chart.

Most of the problems with this particular device occur if a piece of material becomes lodged in the airway. This can result in erroneous readings because of the increase in pressure required to either blow out or seep around the obstruction.

Since both of these methods are essentially mechanical, it should be apparent that considerable maintenance is required to assure that meters are functioning correctly.

LOCATIONS

Regardless of the kind of flow monitoring device being used in the sewer line, it should be obvious that one major requirement for the site must be met: the monitoring device must be able to record a representative measurement of the flow in the reach of pipe. Unless the monitoring site offers the ability to obtain a representative measurement, any data collected by that monitor is useless since it obviously will feed erroneous information in calculating the flow.

When siting a flow monitoring device, the investigation of the site should reveal that there are no obstructions, either immediately upstream or downstream of the monitor location. Obstructions upstream could result in either a reduced or increased level because of the phenomenon of hydraulic jump and the location of the meter with respect to the jump. An obstruction downstream could result in an increased level measurement because of backwater. Besides the possibility of one of the two phenomena being present because of constant fluctuation of the flow in the sewer line, a partial obstruction could cause an even more pronounced surging condition than that which actually transpires in the sewer line because of fluctuations in natural flow.

In addition, to have a clear flow way there must be no major sags or bellies in the line immediately upstream or downstream from the monitoring point. The change in velocity due to the bump or belly will influence the apparent level of flow in the line. If the monitor is one of the new level velocity meters, the velocity recorded will be either higher or lower than the average velocity of the line because of the effect of the bump or belly.

DYE DILUTION

Another method of determining flows in sanitary sewers is a technique known as dye dilution. Here, either a dye or a chemical compound is fed at a known rate into the waste stream. At a predetermined point downstream, samples are taken and allowed to sit for approximately thirty minutes so that the solids can settle out. Then, in the case of dye, the

sample is run through a chemograph and flow is determined from the dilution of the dye with respect to the original concentration fed into the waste stream and the flow rate of the dye.

In the case of a chemical introduced in a known concentration into the waste stream, two kinds of grab samples must be obtained. The first involves analyzing the waste stream to determine the concentration of the known chemical compound prior to injection of the tracer into the waste stream. The second sample is tested to determine the concentration of the waste stream at a point downstream from the injection point. The variations in concentration of the tracer chemical can be equated directly to the volume of flow during the injection period.

ELECTRONIC DEVICES

Finally, there are the electronic devices which, although not as susceptible to the solids present in the flow, do present other problems which are in some cases just as bad. The simplest of the electronic measurement devices record depth of flow only. Generally, a transducer is mounted on the bottom of a calibrated flow way. The transducer is connected to a recording media, either an electronic or strip chart recording. The voltage which travels through the transducer is directly related to the depth of flow much like the float relaying depth of flow to the strip chart.

In the same way, ultrasonic sound waves can be used to gauge depth of flow by the reflection of the sound wave from the interface of air and water. Because of the electronic and electrical nature of these devices, extreme variations in voltage can result in variations between the calibrated calculated depth of flow and the actual flow. In addition, because most electronic components are very susceptible to voltage surges, a sharp voltage spike could burn out the equipment resulting in complete loss of flow data.

The first electronic measuring devices experienced a considerable number of problems in obtaining accurate and consistent flow measurements. Three years of on-site experience has eliminated, for the most part, the majority of these problems. But as with all recording devices, electronic or mechanical, the user should determine for himself, periodically, the relationship between a measured flow through the sewer line versus what the recording instrument indicates. If a significant variation is revealed during that check, then the instrument should be observed and, if necessary, recalibrated.

While depth of flow can indicate flow in a sanitary sewer line, there are situations where depth of flow is not an adequate "known" for calculating actual flow quantities in the sewer. Often, because of physical limitations of the system, sanitary sewers are found under high flow conditions, actually surcharging; that is, the water surface in a manhole is actually higher than the crown of the transport pipe. In situations

where small pipes enter larger collectors at their invert, flow often can backup up the smaller pipe because of differences of hydraulic head between the two lines. Under certain surcharge conditions, the velocity in the pipe may very well be zero, while in the condition of differential pressure heads, the flow in the smaller pipe may actually be in the opposite direction. If only a depth-of-flow meter is utilized to record flows, the variance between the calculated and actual flow rates could be extreme and 100 percent off if the flow is actually going in a reverse direction.

Because of this problem, it is widely acknowledged that the only accurate method of determining flows in a sewer line which is susceptible to surcharge and backflow, is to use not only a depth of flow meter, but also a velocity meter. The velocity meter uses a screw, or propeller within the flow coupled with a depth-of-flow meter, to show the relationship between the depth-of-flow being measured and the actual velocity of the flow. These two factors plugged into an equation will give the best evaluation of actual flow in the line. Again, because of the necessity of using mechanical devices in the flow, the velocity meter must be maintained regularly so that results are consistent.

VELOCITY METERS

Just as electronics have invaded the area of depth-of-flow monitors, several electronic velocity measuring devices are on the market. They use the Doppler effect for measuring velocity; that is, they send a sound wave into the flow. The sound wave is reflected back to the receiver and the change in the wave pattern is measured and is related to the velocity of the flow based on the characteristics of the returning wave as compared with the characteristics of the transmitted wave.

HOUSE LATERALS

Precise flow determination from leaking house laterals is difficult and, at best, an approximation due to the inaccessibility of the point of discharge from the house lateral to the street sewer. Flows from these sources can only be measured easily at some convenient point, generally the nearest downstream manhole. Utilizing various kinds of measurement devices, described in other sections of this manual, mass flow from a sewer reach, which includes house connections or house laterals, can be estimated by eliminating the upstream flow and then measuring the flow in a reach bounded by two manholes. To eliminate upstream flow, it must be temporarily blocked at an upstream manhole being careful not to create flow backup into adjacent basements. Since house lateral connections to the street sewer are inaccessible, one can only estimate initial overall leakage of the reach. This is complicated by the fact that while total flows suspected to be due to infiltration or flow during rain periods may be measured in this way, a portion of the flow may in fact be running wastewater or leaking plumbing fixtures feeding into to the system from an adjacent building mistakenly considered part of the infiltration.

Only when one can actually observe the house connection using television techniques, can a subjective determination of flow from building sewers be made. The flow attributed to the house connection, as compared to ground water, visibly entering the street sewer in that reach, can also be determined. But this is not always possible, particularly during low flow periods. Experienced observers report they are able to estimate flows precisely by visually observing a connecting lateral; however, there is some doubt as to how precise this practice is since it is subjective at best. While such a subjective analysis of service connections does have some validity when evaluating sewer reaches with only one or two leaking connections and serving single family residences, further complications are seen in other circumstances. In some cases, internal inspection may reveal more service connections than can be accounted for by surface structures along the sewer reach being inspected. It must then be determined if these unused connections (house laterals) are abandoned or are merely stubs which were never connected to structures, and if in fact they are leaking at any time. Frequently, riser connections are observed leaking, but in densely populated areas it is hard to tell which building or buildings are connected. Television inspection in sewers where industrial, commercial, or apartment complexes are tributaries complicates the task of visually defining leakage because process water, cooling water, or plumbing fixture leakage may appear to be infiltration.

There is no exact way to measure house lateral flow (particularly if such flow appears as a damp area rather than an observable stream of water entering the sewer from the house lateral). This is further complicated by the fact that at times ground water levels vary, depending on seasons and the amount of rainfall, and may create entirely different hydrostatic conditions about the piping system, resulting thereafter in changes in the amount of measurable flow within the sewer system.

Various types of sewer infiltration/inflow control equipment, including measuring and metering devices, are presented in U.S Environmental Protection Agency, "Sewer Infiltration and Inflow Control Product and Equipment Guide," produced by Municipal Environment Research Laboratory, Office of Research and Development (EPA 600/2-77-017c,), U.S.E.P.A., Cincinnati, OH 45268, July 1977.

PILOT PROGRAM REHABILITATING HOUSE LATERALS

In 1982-83, Salem, Oregon, conducted a pilot rehabilitation project in an area which had been constructed substantially between 1966-68. The initial system evaluation was conducted by Westech Engineering, Inc., in conjunction with the City of Salem. During the investigation, a self-leveling weir box was built which could be positioned adjacent to the lateral entrance into the sewer main, and which would rechannel the entire flow from the lateral through the weir box, and subsequently measure the total flow coming from the sewer lateral by observing a notched weir with a television camera positioned downstream.

During the investigation period, flows ranging from 10 gpm (37.8 l/min) to more than 50 gpm (189 l/min) were measured using this method. Flows in excess of 50 gpm (189 l/min) could not be measured adequately, as the weir device used to measure flows had a capacity less than 50 gpm (189 l/min). In addition, it was difficult to correlate the lateral flow measurements because it took several days to monitor all of the laterals in the test section. Some of the laterals which were monitored several times, several days apart, showed a wide variance in the volume of flow coming from the house lateral.

Another more commonly used method of determining flow from house laterals, is that of blocking flow at an upstream manhole and measuring the flow at the next downstream manhole. When the upstream manhole is totally plugged it is obvious that the only flow being measured at the downstream manhole would be that which infiltrates into the main line plus any inflow and/or normal flow from the house laterals on that stretch of line.

As imprecise a method as this is, it is better than no method at all. The imprecision comes from the inability to adequately and correctly estimate the flow coming from each individual house lateral so that a proper, priorties-of-repair can be made by determining which laterals are serious offenders and which not.

Compounding the problem are stretches of sewer line which are constructed in residential areas. Televising the line could help determine that there are more taps into the main line than adjacent structures. While some of the newer television equipment has the capability of right angle viewing, most equipment can only look straight ahead. That being the case, it is impossible to determine whether the additional taps are merely stubs that have never been connected and do not leak, or are connections of old structures that have been broken off, and in fact, leak substantially during wet weather.

It is an accepted premise that house laterals, probably are a major source of inflow because of the nature of the construction techniques that predominate in the building of house laterals. As a rule, house laterals are constructed according to the standards of the building code which are in effect in the municipality at the time; and not in accordance with standard specifications for construction of main sewer lines.

The building contractor will generally lay sewer laterals on the minimum grade allowed by the building code until the property line is reached adjacent to the main sewer. The contractor will determine at what elevation the main sewer is and break the grade of the lateral at the property line so that the lateral will intercept the main sewer line at the proper elevation. The final run of the building lateral has been known to achieve slopes greater than 1:1.

An additional problem in building sewers is the connection which many contractors make with the main. If stub outs, either in the form of a

tee or a wye are provided, the building contractor may or may not use those particular appendages. In some cases building contractors have been known to stub their building lateral into the main line within 4 or 5 ft (1.2 or 1.5 m) of an existing wye or tee because that was where they intercepted the main sewer. This results in a makeshift connection with the main sewer which after a short period generally is no longer watertight. Also, because of the steep slope from the property line to the main sewer, settlement of the building lateral can result in joint displacement and even totally open joints due to line slippage. During high water table periods, those open joints and taps will result in a good deal of infiltration in the sanitary sewer.

Another problem in estimating flows from house laterals is that during high ground water conditions, and increased flow in the sanitary sewer, there is no easy way to observe adequately the flow coming from individual house laterals. Direct observation through the use of televising equipment is generally not possible either because during those periods the sanitary sewer is normally flowing at least three-quarters capacity making the television camera useless.

ACCURACY

Types of Monitoring Errors and Their Magnitude

Sewerage monitoring inaccuracies can be broken down into two categories: error in human observation and imprecision in recording. An example of the first is the estimation of a pipe's flow depth with an engineer's ruler. An example of the latter is the monitor's recording of that depth. Each of these contains several sources for error.

Error In Human Observation

The calibration of an open channel flow meter involves three sets of measurements: measurement of the depth of flow of the sewage for the purpose of calibrating a particular device, the measurement of the pipe's diameter, assuming the pipe is round, and the measurement of friction, slope, and Manning's "N" at that location (discharge calibration). Of the three, the discharge calibration involves the most measurements and is prone to the most errors. The other two, while seemingly inconsequential in their execution, have great significance in flow monitoring results.

The error inherent in measurement of the depth of flow (DOF) of sewage in a pipe arises from the resolution of the device used to scale the distance, the hydraulic conditions of the flow, and basic errors in human judgment. The engineer's ruler has a stated resolution of 0.01 ft (0.3 cm). At velocities of greater than 2.00 fps (0.6 mps), a tail water rises up the side of the ruler and causes a condition where the last few hundredths of a ft of the measurement must be estimated. Further more, a lapse of several minutes between the monitor's calibration adjustment and

the observation will cause a time lag error of several hundredths of a foot. Finally, the misplacement of the scale onto or around the pipe invert will cause additional error. The value of the error of this measurement has been observed to be approximately four percent of the DOF. This percentage was estimated from observed adjustments to the Washington Suburban Sanitary Commission's telemetering system. Once the meter is considered "calibrated," that value of four percent of the calibrated DOF will be assumed throughout the metered flows.

The measurement of the sewer pipe's diameter is generally accomplished with the same scale as the DOF measurement. This error is somewhat smaller than the DOF measurement as less judgment is involved. The value of the error is estimated at the resolution of the ruler 0.01 ft (0.3 cm). Field conditions and manufacturer tolerances call for the measurement of pipe diameter.

Flow conversion in open channel flow monitors is most often performed using the familiar Manning equation:

$$Q = ((1.486)S^{(1/2)})(R^{(2/3)})A/(He)(N) \qquad (1)$$

Where

Q = Flow (cubic feet per second)

N = A roughness coefficient, or Manning's "N" (at full pipe)

He = Hydraulic elements adjustment factor for the variation of Manning's "N" with depth

S = The friction slope

R = The hydraulic radius (ft)

D = Pipe diameter (ft)

A = Cross sectional area (square ft)

The unknown constants N and S can be combined into one constant (S/N) and then determined using velocity measurements. A variety of techniques are available for converting velocities into a calibration value; however, three techniques will be mentioned here.

A very prevalent technique of estimating energy slope $(S^{(1/2)})/N$ of an open channel meter is to obtain the velocity at four-tenths of the depth of flow; assuming the obtained velocity is the average within the total discharge. Another technique is to attempt to find maximum velocity within a flow and convert it into an average velocity.

Using these single velocity techniques, errors may be as high as 35

percent. Both techniques are extremely error-prone and should be avoided. It is better to profile the flow and then average the obtained velocities or fit the data with one of the techniques available in the literature. After an average velocity is determined, equation (1) is either manipulated algebraically to yield (S^(1/2))/N or a value for Manning's "N" is assumed and S is derived.

The techniques have several built in sources of error. First and foremost is the error inherent in the velocity meter used. All velocity meters will lose their accuracy in time unless they are calibrated regularly. Calibration of electromagnetic (EM) velocity meters is generally done by the manufacturer and can be very important. For example, in a three-month period, Washington Suburban Sanitary Commission had to calibrate it's EM meters three times after extensive use. The calibration drift encountered was from 12-15 percent of full scale. Propeller-type meters can be calibrated by the user, and this should be done regularly. The stated accuracy of calibrated velocity meters (EM and propeller) is two percent of scale.

The collection of quality velocity data is very difficult. Domestic sewerage contains a large amount of suspended solids which will foul both the propeller and EM velocity meters. Studies of the EM velocity meters have shown that at least 8 seconds of uninterrupted flow are required to obtain good readings. Propeller velocity meters require a somewhat longer time--observed to be between 15-20 seconds--to respond, because the revolutions of the propeller are processed into instantaneous velocities. Erroneously low velocities are the norm, particularly in heavily concentrated sewerage. A typical velocity profile will take from 10 to 15 minutes to collect. Assuming a good velocity is obtained, an additional two percent in error may occur due to typical hydraulic fluctuations during this period. The error calculated for the velocity applies only to the estimation of the energy slope's error. The error in the energy slope will remain systemic throughout the conversion of the DOF's to discharges.

Imprecisions in Recording Devices

The error inherent in the actual flow monitor can be broken down into two categories: errors in recording and errors in recorded resolution. An example of the first is the error of the device which records the depth of flow. An example of the latter would be the precision of a circular chart for a dipper or the amount of computer storage used to store a single DOF in a microprocessor style flow meter. Not included in this discussion are the time response errors of flow monitors or the errors in noncontinuous flow monitoring.

The manufacturer's literature accompanying flow monitoring devices states the error of the depth sensor for idealized situations and the resolution of the

recording device. Just as an improperly installed flume will give erroneous readings, a poorly installed flow monitor will yield poor results.

With the advent of computerized monitoring systems, errors in recording resolution of these devices are negligible compared to the above-mentioned sources of error. The same cannot be said of circular and strip recording devices. In these, the error is that of the recording media or the minimal divisions of this media. The reasoning behind this last statement is that the width of the recording pen line together with the variations in the travel of the recording media result in a line on the chart which only closely approximates the actual conditions prevailing in the line at any time. This information is then interpolated by eye to obtain the final readings used in subsequent computations.

Error Propagation in Flow Monitoring

The results of the depth and velocity discussion are summarized in Table 3.

TABLE 3.
LISTING OF ERROR SOURCES AND THEIR VALUES

ERROR SOURCE	ESTIMATED VALUE	EQUIPMENT TYPE
DOF Calibration	4% of (calibrated) DOF	
Pipe Diameter	0.01ft	
Velocity Measurement	7%	
DOF Sensor	0.01ft	Pressure Transducers
	0.01ft	Ultrasonic Dippers
	0.05ft	Floats and Electric Current Dippers
Recorded Resolution	~0.0	Monitors employing ROM (Read Only Memory) Storage
	0.1 in. - 0.5 in.	Strip Recording

Error is propagated throughout any system of equations in a probabilistic way. Some of the errors mentioned above are random and may assume different values throughout the collection of the data. An example would be the measurement of the depth of flow. Each time this depth is measured, the error of the sensor can either take on the higher or lower value. Once a meter has been calibrated, the errors in the calibrated depth of flow and energy slope will be constant. Thus, in order to estimate the error in flow monitoring, one must

first estimate the "system errors," then calculate the random errors in the data collection system. The four percent depth of flow error, a 0.01 ft (0.3 cm) pipe measurement, will propagate throughout the "energy slope" and the depth of flow calculations.

One way to view the propagation of error is to use the coin toss analogy. In estimating the energy slope, three error points are involved. To calculate an error based on the higher and lower values of the error would negate the possibility of one error being in apposition to another. Each error has an equal possibility of assuming its higher or lower value. Thus, median error must be calculated. Table 4: ERROR ANALYSIS SCHEME FOR THE ESTIMATION OF ENERGY SLOPE presents a scheme of estimating the error of energy or friction slopes.

TABLE 4.

ERROR ANALYSIS SCHEME FOR THE ESTIMATION OF ENERGY SLOPE

VALUE ASSUMED BY ERROR TYPES			**VALUE
VELOCITY ERROR E1	PIPE DIAMETER MEAS. ERROR E2	DOF ERROR E3	
H*	H	H	E(H,H,H,)
L*	L	L	E(L,L,L,)
L	H	H	E(L,H,H,)
H	L	H	E(H,L,H,)
H	H	L	E(H,H,L,)
L	L	H	E(L,L,H,)
H	L	L	E(H,L,L,)
L	H	L	E(L,H,L,)

*H = Upper bounds of error, L = Lower bounds of error.
**E (A,B,C), i.e., E(H,H,H) = the value of the estimate with all of the errors assuming their high range minus the slope estimate.

Table 4 is simply the combination of the three random errors in the estimate of this parameter. In terms of combinations terms, we have 2 x 2 x 2 = 8 possible combinations. A simple error, such as a series of measurements, should have an approximately normal distribution of error and, thus, an equal higher or lower range. The errors will assume, as in the toss of a coin, either higher or lower ranges of their respective values. The calculations of the propagation of error within a single depth of flow are rather simple, but should be performed throughout the range of depths encountered in a sewer flow. Thus, the problem is well suited for computer solution. A worked example is included below to demonstrate the method of solution proposed.

A monitoring site has been set up in a 24 in (0.6 m) pipe. Using a profiling technique, the average velocity was estimated to be 3.5 fps (1.1 m/s) (I-.07%) at a depth of flow of 14.3 in. (36.3 cm). The pipe was remeasured at the point of data collection as 23.9 in. (60.7 cm) (I-.1%). The monitor, a ROM-reading type with a pressure transducer, was calibrated at a DOF of 13.60 in. (34.5 cm) (I-.04%). What would be the energy slope and the upper and lower bounds of the estimate?

A) Estimate the error of the energy slope, using values from Table 3 and the scheme in Table 4.

A1) The estimated central value of the energy slope is:

$(S^{(1/2)})/N =$

$V/((R^{(2/3)})(1.486))=$

$((1.21)(3.5))/((.6731)(1.486))=4.234$

A2) Calculate the error of the estimate with the upper bounds of the stated errors:

V = 3.5+(0.07)(3.5) = 3.745 (upper value velocity)
D = 23.9+0.1 = 24 (upper value diameter)
DOF = 14.3+(0.04*14.3) (upper value flow depth) =
E(H,H,H)= ((1.21)(3.745))/((0.6827)(1.486))-4.234 = -0.233

A3) Calculate the error of the estimate with the lower bounds of stated errors:

V = 3.5-(0.07)(3.5) = 3.255
D = 23.9-0.1 = 23.8
DOF = 14.3-0.04(14.3) = 13.728
E(L,L,L)=((1.21)(3,255))/((0.6627)(1.486)) -4.234 = -0.235

A4) Similarly the remaining error combinations are calculated:

E(L,H,H) = -0.351
E(H,L,H) = +0.305
E(H,H,L) = +0.355
E(L,L,H) = -0.288
E(H,L,L) = +0.367
E(L,H,L) = -0.244

For this case, a better representation of the energy slope would be:

$$((S\hat{}(1/2))/N = 4.2\ (\pm)0.3$$

The error of a discharge would be estimated by repeating all of the possible combinations of error (sensor resolution, DOF calibration error, pipe diameter error). Data recording error (16 combinations) throughout the (R(2/3))A portion of the Manning equation then combining the resultant error with the slope and respective error to achieve the resultant discharge and error.

Other Open Channel-Discharge Formulae

Research has been conducted into the development of improved open channel-flow formulae.

Pomeroy proposed a manipulation of the Hazen-Williams equation which fits existing field discharge-slope data more accurately. The equation is expressed:

$$Q = (K\hat{}(1.316))(S\hat{}(0.54))(A\hat{}(1.316)) \quad (2)$$

where

K = Constant of friction
A = Area
S = Slope

In examining the equation, the area of the flow is combined with the hydraulic radius yielding, perhaps, a less sensitive equation. Table 5: FLOW ESTIMATES OF TWO DIFFERENT FORMULAE, presents the results of a comparison of the result of sensitivity analysis of a hypothetical flow monitoring situation as modeled by equations 1 and 2.

TABLE 5.
FLOW ESTIMATES OF TWO DIFFERENT FORMULAE

DEPTH OF FLOW	MANNING DISCHARGE	MANNING ERROR	POMEROY DISCHARGE	POMEROY ERROR
(FT)	(CFS)	(CFS)	(CFS)	(CFS)
0.18	0.18	-	0.23	-
0.36	0.75	0.1	0.85	0.1
0.54	1.70	0.2	1.83	0.3
0.72	2.96	0.4	3.10	0.4
0.90	4.48	0.6	4.61	0.6
1.07	6.28	0.9	6.30	0.9
1.25	8.21	1.2	8.10	1.1
1.43	10.27	1.4	9.95	1.4
1.61	12.29	1.7	11.77	1.6
1.79	14.19	2.0	13.45	1.9

Notes: Pipe diameter: 2.15 ft. (+-)0.01 ft., V = 3.5(+-)0.25 FPS at 1.1 ft., calibrated DOF = 1.2 ft.(+-)0.05 ft.

Examination of each prediction shows that each term is within the range of the other. Only better methods of attempting to quantify the required parameters will answer the question of which equation provides a "better estimate" of the flow in a sewer pipe.

SUMMARY COMMENTS

The most common error to occur using an open channel flow monitor is the combination calculated as described in the schemes presented in Table 4. Care must be taken to minimize the error inherent in each item of measurement. The decisions made with flow monitoring data must consider the range of error in the discharge data.

CHAPTER 4

REHABILITATION METHODS

The rehabilitation processes for sewer mains can be divided into several basic techniques. The following is a discussion of six of these techniques with a look at the positive and negative aspects of each, and a discussion concerning the best use of each.

The six basic techniques to be examined here are:

1) Spot repair
2) Reconstruction in place
3) Construction of a bypass
4) Grouting
5) Sliplining
6) Inversion lining

Another would include:

7) Manhole rehabilitation

SPOT REPAIR

Here the object is to determine the location(s) of the problem areas in a length of line, remove the overburden from the line, and take away and replace the damaged areas to bring the line back to a reasonably leakproof condition.

There are many methods of accomplishing spot repairs, some considerably better than others. Many agencies will locate the distress point, uncover the line at that point, wrap a sheet of tin around the pipe, and then encase that section of pipe in concrete. As a rule, this will solve the collapse problem but will not reduce the amount of infiltration/inflow from that point significantly because the joint between the old pipe and the new concrete cannot be made watertight. Groundwater will be able to flow between the encased concrete and the sewer pipe until it reaches the area of distress and enters the stream.

The proper way to do spot repair is to first find the area of distress and uncover, not only the section of pipe which is broken, but also the sections immediately upstream and downstream of that broken pipe section. This is done because the proper method of correction is to completely remove the damaged section of pipe and replace it with a new section, especially if the sewer line which is being repaired is of the premium joint variety. If additional money was spent to purchase that kind of pipe initially, then it makes sense to spend slightly more money on the spot repair to protect the integrity of line by replacing the damaged section with like construction.

Admittedly, it is more difficult to replace one section of the line than it is to cap it with concrete. To do this, three sections, or possibly merely two sections, of pipe must be removed and relaid to complete the repairs. This is necessary because the line is already in place and in order to replace only one section of pipe, the bell will have to be broken on the downstream end. This again would destroy the integrity of the line however watertight it is because of the need to cap the breakage with concrete. To properly replace the damaged section, the free ends of the sections of pipe immediately upstream and downstream must be lifted where the new section of pipe is to be inserted. As the two free ends are lifted, the distance between ends will increase so that a new section of pipe can be slipped over the spigot end of the one and into the bell of the other. Once this is accomplished, then all three pieces of pipe can be lowered onto the original bedding of the trench. Since sewer line generally comes in 4 ft or 8 ft (1.2 or 2.4 m) sections, this could mean that as much as 25 ft (7.6 m) of trench would have to be excavated to accomplish this operation. With sewer lines at depths greater than 4 ft (1.2 m) there is another problem associated with either placing shoring in the excavation, or sloping the sidewalls to prevent collapse into the excavation.

It is obvious why the cheaper and quicker method is used more often, but when the final condition of the sewer line is evaluated, comparing the more time-consuming and expensive operation versus the "quick and dirty," it should be obvious that, in the long run, it is more cost-effective to do it right the first time.

The problems related to this method vary with location. The biggest problem involves the use of major equipment to uncover and recover the damaged line. This requires a crew of several persons, most of whom are idle during the major portion of the digging. Once the digging is completed, the equipment operator then becomes the one who is idle.

Besides the problem of achieving efficient use of the crew, there is the problem of the stability of the line itself. If the line has begun to undergo distress, it's quite likely that the whole line is in less than satisfactory condition. Because of various constraints, there may not be enough time or resources immediately available to renovate all of the damaged sections in a given line that need replacement. Later, the crew often find themselves at nearby location on the same line section performing another repair job within a short period of time. This could lead to duplication of effort in a given area, and consequently to excessive expenditures of both manpower and resources. There are also the added problems of traffic control and interference with other utilities which tend to slow down a job and increase costs.

The advantage is that if there is a section of line which has few problems and only one or two major deficiencies, it may be more advantageous to fix those isolated areas with the spot repair rather than to expend large amounts of resources in hopes of only a small increase in function.

IN-PLACE REPLACEMENT

This leads to the next method of line section rehabilitation, and this involves total replacement in-place. This method is similar to spot repair except that it entails total removal and replacement of a specific run of line. While this technique does eliminate the need to return and repair adjacent sections of line time after time, it does create problems because of the need of maintaining service to the affected users during actual construction. This may result in use of temporary lines, or something of this nature, to maintain continuity of service.

As with spot repairs, the confrontations with traffic and other utilities still exist; however, the problems are now compounded because of the increased area of disturbed ground the project will encompass.

ALTERNATE LOCATION REPLACEMENT

To eliminate the problem of maintaining service while the rehabilitation project is being completed, an alternative to in-place replacement is often used. This involves relocation of the line by constructing a new line to replace the function of the damaged line section. While this may reduce the severity of some of the problems of the two previous methods, it does require the purchase of additional land in order to construct the new line. In addition, it may be necessary to do minor repairs on the existing line to maintain service while the new line is being constructed.

Unless the new easement is located outside of the right-of-way (R/W), the problems of traffic control and utility confrontation will still have to be overcome. Even if the new easement is not in the R/W of the street, the possibility of utility confrontation could still exist.

The major advantage of this method is that the line is now new, and has an expected life far greater than that of a renovated line using most of the rehabilitation techniques being discussed. On the other hand, the first cost of totally reconstructing the line is normally far more expensive than that of renovating it.

Because some of the pipe rehabilitation techniques being discussed here have existed only for a short period of time, there is not enough data to ascertain what the life, and therefore the long-term costs of the rehabilitation project would be. It will be only after enough data has been collected that an accurate comparison can be made of the actual long-term cost of total rehabilitation versus the cost of reconstruction to determine which technique is actually most cost-effective for a given case.

CHEMICAL GROUTING

This leads to a discussion of the more familiar and specialized methods of pipe rehabilitation, the most common of which is chemical grouting. This is a process where some kind of a two-component gel is pumped into and through the pipe joints in the line. Chemical grouting is good only when the line is in a reasonably stable structural condition. It should be recognized that more than a dozen brands of chemical grout are currently available. The user also should be aware that most types are machine dependent. That is, some manufacturers' grout types will not work in other manufacturers' machines.

Chemical grouting begins with the investigation of the system to determine the areas where excessive infiltration/inflow is occurring. Once this is determined, the lines in question must be cleaned. Cleaning is necessary so that the television camera operator can adequately observe the lines and determine where the deficiencies are. The most efficient method available for cleaning sewer lines is the self-propelled, high-pressure water jets. After cleaning televising can then begin. Problem locations are logged on the record using the footage counter, which is coupled with the TV camera, and which enables the operator to accurately locate problems with respect to the distance from the entered manhole.

Within a reasonable time after that, before the line becomes too dirty again, the grout packer is placed in the line, and positioned over the problem area once it is relocated using the TV camera and the footage counter.

The packer has two inflatable "doughnuts," one at each end of the unit, which are inflated, partially sealing the line upstream and downsteam of the pipe joint. The two-part grout is then pumped into the cavity between the packer and the sewer line. Then additional pressure is applied, forcing the grout through the joint and into the fill or any cavity which may exist outside the line. The curing time is allowed to lapse after reducing pressure. Once the curing time is completed (45 to 90 seconds, depending on the material mixture) the joint is air tested to assure that the grout has completely sealed it. If the joint passes the air test, the packer is moved to the next joint and the process is repeated until the line is completely sealed.

If there are large voids outside the pipe, depending on the grout used and its characteristics, a large amount of grout may have to be used before the line is completely sealed. This could be very expensive. In addition, because of the design of the packer, it is almost impossible to seal joints that are immediately adjacent to a service lateral junction because no pressure can be applied. The packer cannot work on a longitudinal crack in the line which extends beyond the "doughnut" for the same reason. Also, the packer cannot seal a joint with more than a slight amount of lateral displacement because of the inability to apply

pressure to the grout.

If the line being rehabilitated has severely distressed areas, these must be corrected using some other method since the grout gives no structural stability to the line and probably would not be usable anyway due to the inability of the packer to pressurize the area.

SLIPLINING

Sliplining is a technique where the sewer line is rehabilitated by placing a rigid liner inside the existing pipe, either by pushing or pulling the liner into place. The liner is generally made of either plastic or fiber glass, and is flexible enough to accommodate small alignment changes in the existing line.

The major problem with this technique is the inability of the liner, as it moves through the existing pipe, to surmount either major alignment changes or obstacles, such as collapsed pipe or projecting service laterals. Such problems must be removed or corrected before the lining operation can take place.

Once the lining is in place, the service connections, (which were located by televising the line before lining and logging their locations), must be dug up and connected to the new lining. This can be accomplished either by (1) digging the connections and "welding" a wye or a tee into the liner and then connecting to the end of the existing service lateral or (2) filling the annular space between the liner and existing pipe and placing a saddle on the outside pipe and connecting the service lateral to it. Regardless of the method used to join the existing service to the new liner, each junction must be dug and treated as a spot repair.

After the service laterals have been reconnected, the problem of the void between the outside of the liner and the inside of the old pipe must be addressed. There are two opinions about what to do about this. One theory says to fill the annular space completely; the other says that only portions of the annular space need to be filled to prevent liner movement. Since the lining technique is a relatively new process, there is not enough data at present to determine which theory is correct.

One point can be made for grouting the entire annular space and that is simply this: With the entire space filled, the structural capability of the line will be increased. If a collapse occurred on a nonfilled liner, there is a good chance that the liner would collapse also since the liner is not as rigid as the original pipe.

This technique is best used where there is little structural instability in the existing line and few service laterals to contend with. It is effective where there is confined space to work in both from aboveground and underground conditions. The lining technique does not have to

contend with other adjacent utilities except for the pit which has to be dug at one end of the line to allow the liner to enter into the existing line.

INVERSION LINING

This technique uses a felt sleeve soaked with a thermo setting reaction-based plastic material. The sleeve is inside out at the start. One end of the sleeve is attached to the end of the pipe to be lined, and cold water or air is pumped into the area of the sleeve, between the sleeve which is inside out and the return part which is right side out. The air or water in that space is then pressurized and forces the sleeve down the line pulling the inside out portion through the center of the right side out sleeve in a continuous operation. Because of the inversion process, it is not necessary to have additional pulling or pushing equipment to facilitate the placement of the sleeve. Beside the sleeve being self-placing, the water pressure forcing the inner sleeve down the line also forces the outer portion of the sleeve into continuous contact with the interior of the existing sewer line.

As it travels down the line, the sleeve is turned right side out so the thermo chemicals are facing the inside of the pipe. Once the sleeve has traversed the entire length of line, the cold water is replaced with hot water in the liner which sets off a reaction of the thermo reactive chemicals, bonding the liner to the existing walls, and creating a solid liner in the pipe.

The drawback here is that the line must be thoroughly cleaned prior to the lining process, and the laterals must be located and logged.

The second problem involves the service lateral connection. While this process has devised a method of cutting (routing actually) the liner from inside the pipe, the accuracy of the cutter has not been sufficiently refined to provide a clean cut into the service lateral and it is time consuming. On the other hand, the total elimination of the need to uncover the service lateral connections in order to reconnect them is a major advantage.

Inversion lining has still another advantage over sliplining. At the commencement of the lining process, the sleeve is very flexible. The sleeve can be introduced into the pipe to be lined through a manhole large enough to allow entry by a man, and therefore, does not require a large pit to introduce the liner as sliplining does. Since the sleeve is flexible, it can also handle larger variations in alignment and displacement than sliplining can.

This is a new process with no significant degree of historical data to fall back on. The process is patented and therefore offered by only a few select contractors. These two facts combined are why competitive

bids will be hard to find if the particular rehabilitation technique has to be bid.

In addition to the previous discussion describing the different techniques of sewer rehabilitation, a flowchart, or "decision tree," is included (Figure 1) with the objective of guiding the user through the decision-making process in conjunction with the most effective materials.

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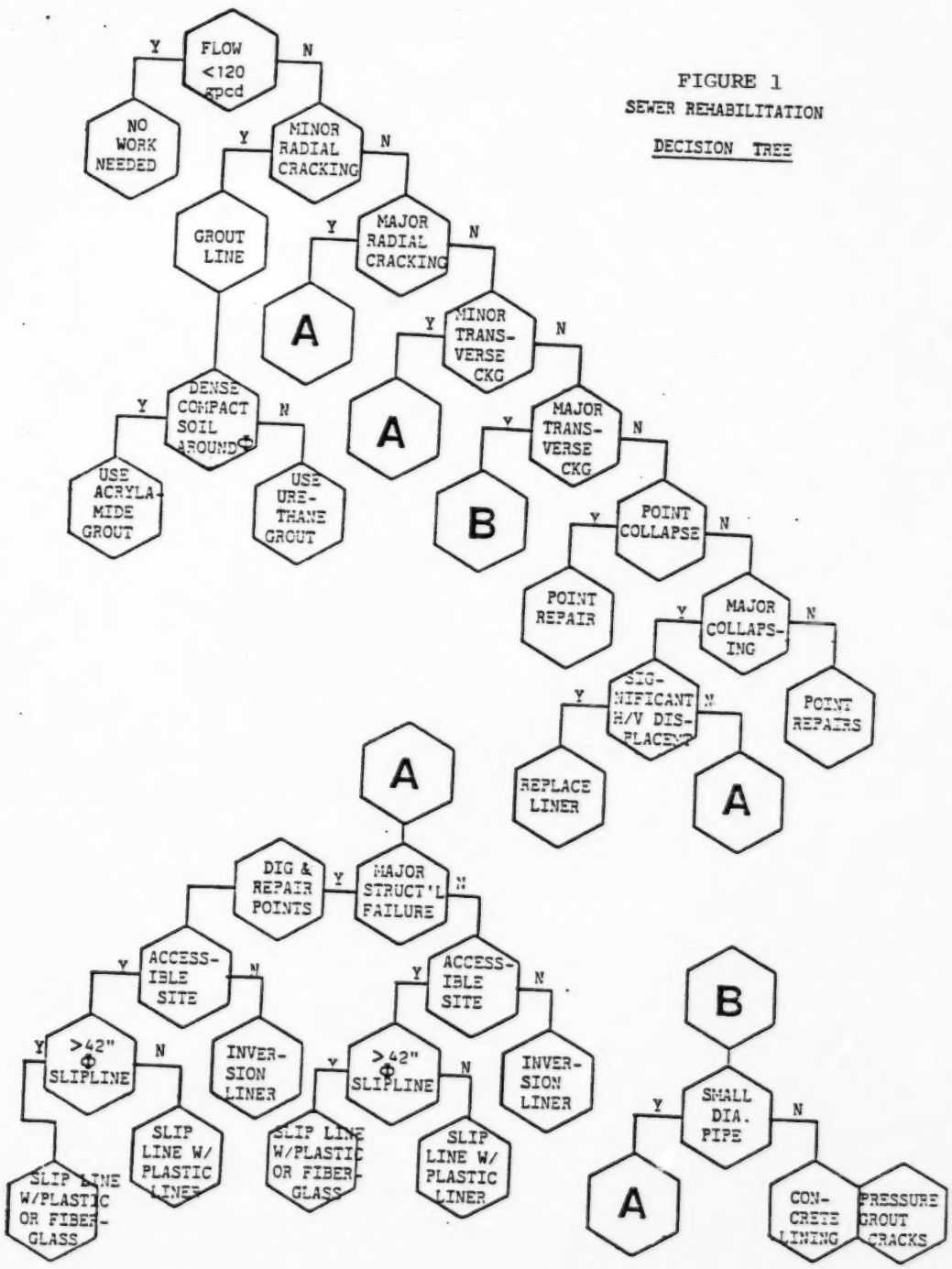

FIGURE 1
SEWER REHABILITATION
DECISION TREE

CHAPTER 5

ECONOMICS OF REHABILITATION

The purpose of this chapter is to discuss problems inherent with rehabilitation techniques currently being used and how they may affect the economics of rehabilitation selection and lead to a more precise cost estimation. In spite of empirical information available from various sources it is best to generate cost figures using a rational approach. While the approach can be local or regional or based on general guidelines, specific and historical cost information used should be as up-to-date as possible. In this matter practitioners, engineers, contractors, specialists, and state agencies can be helpful. However, hard local information to verify actual conditions as they relate to specific problems, schedules, approach, and required success to be achieved should be considered in determining true "Bottom Line" economics. What are some of the problems affecting the economics of rehabilitation?

GENERAL CONDITIONS

Traffic Control

Most sewers can be found within the traveled rights-of-way such as streets, roads, and highways. Therefore, entrance to sewers generally is made via manholes which are also constructed within the rights-of-way. Occasionally these structures can be found within an off the traveled ways such as parkways or in parking areas. Since the grouting and sealing is done from a self-contained van, and the technique requires access from at least two manholes, provision must be made to protect workers from traffic. This is particularly important in heavily traveled ways. Regardless of how minimal the traffic is, for safety's sake there must be some provision and therefore cost involved in providing traffic control. Obviously, the heavier the volume of traffic anticipated the more extensive the traffic control and personnel protection. Traffic control on lightly traveled streets may only require one or two signs, road cones, or such, while traffic control on a well traveled way may require multiple signs, lane closures, barricades, flagpersons, or in some instances, police. Many typical traffic control setups are detailed in the APWA publication "Work Site Traffic Control".

Mobilization

Another factor influencing the cost of grouting rehabilitation is mobilization. This cost relates to marshalling men, equipment, and materials from a central location and transporting all that is necessary to comply with contract requirements on-site and if necessary, removal from the site to a centrally located storage facility. Included in this

cost is the personnel training necessary to insure performance of the tasks in a safe and workman-like manner. Since many grouting projects, as well as other rehabilitation work, are awarded through competitive bidding, the contractor will undoubtedly include other costs in the mobilization costs, such as preparation, insurance, bonds, supplies and inspection crews, etc. These costs are included in the price(s) bid or as a separate item, if provided in his bid-documents. The mobilization factor can have a significant impact on costs, particularly if the work of grouting is relatively discontinuous. Major moves of labor and equipment over wide areas of work can add significantly to overall costs. Also, delays in rehabilitation sequencing requiring removal of idle equipment can also increase costs significantly. Being forewarned of rehabilitation problems and providing for them in contracts can save money claims for extra work at the end of the project.

Line Cleaning

A major problem and cost factor is line cleaning. Sewers must be cleaned prior to all internal operations in order to properly inspect, survey, and subsequently repair the sewer. Cleaning is necessary to remove solids of a wide range of sizes that have settled in the pipe invert and also to remove root intrusion or obstructions that have occurred. Roots can be removed by a number of recognized root removal procedure and control actions. Chemical root control is usually used to prevent or reduce growth of roots. The amount of effort necessary for root treatment is largely dependent upon the amount of root intrusion and obstructions. The remainder of the cleaning costs will be dependent upon the kind of cleaning equipment used,personnel involved, whether it is a mechanical or hydraulical operation and how effective or efficient it is. In either case, a source of water must be available to complete the flushing necessary to clean the line prior to grouting operations.

Sewer debris can vary greatly throughout the sewerage network. This debris or deposition is impacted by rain related inflow from street drainage, interconnected area drains, downspouts, manhole covers, and the like. Interconnections can result in large amounts of transported sand, gravel, or mud accumulating in the sewer. A sewer serving a residential area can contain sediments of organic material, i.e., grease, grass clippings, and food waste generated by garbage disposals. Each type of deposition requires a particular cleaning technique to adequately and efficiently remove them from the sewer. If the sewer run is short, e.g., less than 400 ft (120 m), with accessible manholes at each end of the run, a hydraulically self-propelled cleaning machine often can be used effectively to clean the pipe, washing debris to a downstream manhole where vacuum equipment removes the debris from the system and prevents downstream deposition. If the reach of sewer is longer than 400 ft (120 m) or if manholes are not available or accessible, cleaning may require the more costly use of bucket machines. Whichever method is adopted the debris will need to be removed via a manhole, transported, and then disposed of in an approved location. The disposal of debris, particularly in cases which involve priority pollutants or hazardous materials, may present costly problems.

A sewer vacuum requires a holding tank, and once the holding tank is full, the vacuum must be taken out of service to dispose of the material collected. This, of course, requires stoppage of cleaning until the disposal process is completed. The problem of costly delays can be resolved by providing a storage tank truck to travel with the vacuum (eductor) truck. The vacuum process need not stop as long as the mobile tank truck is available to receive the sewer debris. Therefore, cleaning can proceed uninterrupted. A bucket machine, on the other hand, can be used to load a dump truck and then load another truck while the first dump truck transports the waste to an approved disposal site. A bucket machine, however, works much slower than hydraulic equipment and cost adjustments are necessary. Removal of waste by dump trucks may require trucker with special body structure to prevent drainage to streets during transport from the site.

Depth of a sewer can have a tremendous impact on removal techniques of sewer sediment. If the sewer, for example, is greater than 30 ft (9.1 m) deep, a vacuum truck cannot physically lift the material from that depth. Cleaning must revert either to using a bucket machine or a hydraulic cleaner to move the sediment to the manhole where it is removed mechanically.

Flow Diversion

Depth of flow can often impede the efficiency and progress of cleaning. While a low flow permits line cleaning to take place, heavier flows may require blockage and/or diversion of flow. A sewer flowing half to three-quarters full would require flow diversion during the cleaning activity. A sewer flowing three-quarters full will reduce the scouring action of hydraulic equipment or impede bucket machinery from efficiently removing debris due to boundary action. During low flow upstream sections may be carefully blocked making certain that flows do not back up into adjacent connectors. This type of flow blockage is relatively inexpensive but may require work interruption because of upstream flow buildup. A more costly but safer technique, particularly for heavier flow, is to bypass pump. This can be costly if needed around the clock. Consideration must be given to flow control under any condition to improve efficiency of the cleaning operation.

Condition of the System

A heavily deteriorated sewer can be damaged further by hydraulic or mechanical cleaning. If a sewer is found to be cracked or there are cavities present in the pipe, the action of a hydraulic jet could further displace portions of the sewer. Furthermore, older joints, particularly grout could also be displaced and increase sewer infiltration. The danger is potential collapse or at least, deposits of surrounding backfill entering the sewer. If, for example, house connections have been permitted and connected to the sewer by a practice known as stabbing, any mechanical cleaning equipment used could be caught causing damage to the line or requiring spot excavation to free it.

The difficulty inherent to cleaning a deteriorated sewer is that the

actual deterioration is discovered too late. Since it is necessary to clean a sewer prior to internal inspection (TV), the very act of cleaning may cause further damage to the system. Any suspicion of structural damage should be investigated carefully prior to committing the line to a full-blown cleaning activity. This additional precaution can often reduce contractors' claims and general arguments over cause of damage during the actual rehabilitation work.

One approach occasionally used, particularly in larger systems, is use of a testing program. A representative area of the entire system is selected to be investigated in-depth to determine, among other information, condition of the system, effective cleaning and rehabilitation techniques, success of various methods, and most important, a range of contractor prices for the various approaches. The test program also provides an insight into special problems that may be anticipated in preparing major rehabilitation contracts.

In smaller systems, of course this would not be practical and would require very detailed investigation where pipe deterioration may be involved. In this case, attention to service records of pipe blockage or chronic street settlement may provide some clues. A firm understanding of the age and history of the system can result in substantial savings in the cost of the rehabilitation phase.

Miscellaneous Factors

Weather will always remain a variable factor in its effect on the work. The problem is obvious: the worse the weather the longer it takes for particular jobs to be performed and, therefore, the greater the cost. Adequate time should be allowed for the work with due consideration given to inclement weather.

After cleaning, scheduling of the inspection phase should closely follow. All cost factors for cleaning must be taken into account while inspecting, including the costs of safety. Personnel entering the sewer must be protected and assured of ample fresh air and a safe nonexplosive atmosphere. This means special ventilation, safety equipment and special training for personnel. Personnel security in high crime area may be an important factor and in certain circumstances can affect the economics of a project. The need for night work can add to that problem too.

Finally, documentation required during inspection should be defined. This can affect overall costs. The manner and degree of this documentation/records should be clearly defined.

REHABILITATION TECHNIQUES

Sealing and Grouting

Sealing and grouting is perhaps one of the most convenient and relatively cost-effective method of rehabilitation available today. Nevertheless,

there are problems attending this approach which add to the costs. General conditions and type of cleaning procedures employed can and do affect the overall costs. Once the cleaning and inspection phases are completed, the rehabilitation work should begin shortly thereafter. All of the preceding factors should be taken into consideration in estimating the cost of chemical grouting as well as other factors specifically related to this technique, such as the type of grout to be used. Some chemical grout is more expensive than others and, depending upon specific problems and a application in a line, it may be necessary to use one type of grout instead of another as discussed in Chapter Five, Rehabilitation Methods. The cleanliness of a pipe has considerable impact upon the progress and effectiveness of the grouting operation. Debris can impede progress of T.V. camera and packer. Impound water can make clear observation and precise judgment of interpreted conditions more difficult. Grease, for example, on pipe walls can produce glare impairing clear video observation. Furthermore, certain chemical grouts are less apt to adhere to pipe that is dirty. Therefore, more effort must be expended to guarantee seal of a joint.

Other internal conditions affect the efficiency of chemical grout operations, such as, settled or misaligned pipe affecting internal passage of grouting equipment. Of course, the degree of displacement is important. A slightly displaced joint will not have the same economic impact upon the grouting procedure as a severely offset joint. The more severe the displacement the greater the difficulty in moving the packer through the line, and, of course, the wider the joint the more difficult it is to effect a seal, irrespective of the type of chemical grout employed.

The number of service laterals, as well as the type of service, has a major impact upon grouting costs. If the service laterals are stabbed and sealed into the sewer, then depending upon the penetration and interference of the service laterals it may be difficult, if not impossible, to grout at or near the service lateral. Depending upon the depth of stab, the grouting machine may have difficulty in proceeding past the interference. The packer with its limited clearance between the inside walls of the pipe is impeded from travel in the pipe by a relatively small service lateral penetration. Care also must be exercised to prevent damage to the service lateral so installed.

The structural condition of the pipe can most certainly impact the grouting operation. A badly cracked or fractured pipe may not permit chemical grout repair. Other methods may be more appropriated. Assuming the structural condition is such that grouting has a good chance of success, then the line must be isolated (by placing plugs at the extremities of the pipe) in order that the grout be forced through the cracks and allowed to seal. In other words, for chemical grout to work the cracks must be isolated and sealed. Longitudinal cracks are difficult to isolate, particularly if they are extensive and occur along several pipe sections.

If the line is seriously defective structurally, the sealing rings on the packer unit when expanded could create further damage by displacing the

pipe, resulting in a future collapse. Prudence and caution in this instance can be translated into increased cost of operation. This kind of problem most probably would call for spot repairs (external excavation and repair), performed on the severely deteriorated pipe sections prior to internal grouting. Spot repair is one of the more expensive techniques if evaluated against the amount of work accomplished. Where there is evidence of a severe defective structural condition, an economic analysis of all things considered may logically lead to use of another rehabilitation techniques.

Sliplining

This technique, as with other rehabilitation methods, requires consideration of the common factors presented affecting the economics of the operation which have been previously mentioned. Sliplining requires that the line be clean, that traffic be controlled, and so on. Sliplining is a technique which employs the insertion of another pipe, that passes through an outer pipe unimpeded. There is, however, an additional procedures peculiar to sliplining, that must be performed; "proving" the line. Proving a line is accomplished by winching a dummy section with a conical taper through the sewer to determine if any longitudinal or transverse changes in the line are extensive enough to prohibit the movement of the slipline along the sewer reach. In some cases, proving may actually adjust some of the minor displacements enabling the slipline to proceed unimpeded. On the other hand, if proving cannot correct small structural problems, then spot repairs must be accomplished prior to the slipline process. Proving a line will also delineate those service laterals which have been stabbed into the line and cause interference. Any horizontal or vertical misalignments or joint displacements which will hamper sliplining also will be defined. Preliminary techniques adding to the cost of this work may require internal cutting of proturberances. Of course, careful preliminary evaluations should be made to project the most effective rehabilitation method needed dependent upon active conditions. A firm understanding of the evaluation process of actual conditions can result in a considerable cost savings during preparation of rehabilitation contracts.

The economics of sliplining is affected by the materials used or the liner type. Rehabilitation should not reduce the sewer capacity to any greater extent than is absolutely necessary. Since sliplining is generally performed with either plastic or fiberglass, the diameter of the liner should be as large as possible and still fit inside the existing sewer. Depending upon the structural condition of the existing sewer main, the design of the slipliner may incorporate an increased wall thickness to compensate for potential stress be expected to be exerted on it. The wall thickness of the slipliner could be increased where structural stability is of major importance and infiltration is excessive, although some of the effective area of conveyance may be reduced by the introduction of the slipline. The relative smoothness and continuity of the new pipe wall and its lower coefficient of friction can allow similar, if not greater capacity, than the original impaired pipe section. Keeping this in mind, the right combination must be found for this job. There are various strengths of plastic liner available on the

market, however, as the specified strength increases so does the cost. Generally, as the strength of a liner increases, so does its weight. This, of course, has an important effect upon the cost of shipment of the pipe from the manufacturer or distributor to the job site; and to a lesser degree, cost of handling on the job. Consideration must also be given to the technique and cost of joining (welding) and trimming various types of slipliners.

Prior to a slipline insertion, an insertion pit is necessary, since the new pipe does not bend to any substantial degree. A ramp must be built from ground level to the sewer elevation. As the sewer depth increases, so must the depth of the insertion pit. Therefore, the volume of excavated material dewatering, soil stabilization, etc, increases. Deep sewers present a special problem of long ramps to allow insertion of the liner into the sewer main with a minimum of bending. The sewer depth also impacts the kind of equipment necessary to dig the insertion pit. A shallow line perhaps would require only a backhoe and two man crew. An extremely deep line could require the use of a bulldozer or similar earthmoving equipment to construct the required ramp, trucks to move earth, pryloaders and other large excavating equipment with the concurrent increase in crew size and substantial increase in the amount of time and space necessary to prepare an insertion pit. At depths greater than five feet there is the additional requirement to either slope back the sides of the insertion pit to stablize grades; that is the angle of repose for the excavated soil, or to brace or shore up the pit so that there is no danger to workmen at the bottom of the pit from sidewall collapse. The installation of shoring not only is time consuming and costly, but could create delays due to bracing obstructions during the sliplining process. Properly placed, however, the shoring should have very little impact upon the sliplining operation other than its cost of installation and removal.

Because there is considerable construction activity in the pit bottom and ramp, temporary paving of the bottom could prevent excessive dirt or mud from being picked up by the liner and carried into the sewer line. The obvious reason to avoid large amounts of debris or material being carried into the sewer is to remove the possibility of the liner binding and causing costly delays.

Depending upon the groundwater condition, dewatering facilities should be considered and available to keep the pit dewatered, reducing the possibility of mud and other material being washed into the sewer. Care should be exercised at night and over the weekend to maintain dewatered conditions during cessation of construction activity.

Insertion liners are usually delivered in lengths of approximately 40 ft (12.2 m). Equipment must be present at the the job site to weld the sections of pipe together to make a continuous liner for insertion into the sewer to reduce extraneous flows. Since sewer mains normally run for 300 to 600 ft (91.46 to 182.92 m) reaches (manhole to manhole), insertion projects normally do three to five reaches or lengths at a time. This continuous length is accomplished by fusing the end of the pipe together

electrically. The type and thickness of the liner pipe determines the power requirement necessary to perform the required heat weld.

The heavier the pipe liner the larger the crew necessary to handle the work and the fewer the number of welds a crew can do in a day's time. As the pipe size increases the required time and cost of the job increases.

The actual installation of the sliplined pipe has several factors worth considering. As the pipe size increases and as the amount of horizontal and vertical displacement increases, the size and power of the winches required to pull the slipliner must also increase. Winches are generally used since pulling tends to reduce the diameter of the front of the liner, making it somewhat easier to pull the liner through the main. Pushing the slipline may be successful for short runs. The particular reach of sewer being rehabilitated should determine the cable length necessary to execute the insertion and will also determine the number of guide pulleys necessary to allow the insertion pipe to travel freely along the reach.

Since the cost of an insertion pit is a major percentage of the total cost of the job, a single manhole-to-manhole pull is normally avoided unless there is only one section of pipe in need of rehabilitation. That can be costly particularly in a deep sewer. The sliplining operation generally is planned for several sewer reaches at a single pull. There are some limitations to length however. As the length of pull increases there is an increasing danger of stretching the pipe beyond its deformation limit. Additional internal surface drag or friction can cause "freezing up." The slipline pull is usually attempted as a continuous effort to avoid the danger of "freezing." Costly freezing time should even under the best conditions be anticipated. Proving the line, as you can see, may appear to be costly at first but it can save considerable time, effort and money in the long run. In some cases, friction can be overcome by initially coating the outside of the liner with lubricant during the insertion process. A continuous pull is important, nevertheless in some cases of substantial pipe deformation, it may not be possible to overcome the friction force and start the liner moving again once the pull has been discontinued. The liner may have to be withdrawn, if possible, or an even more costly approach from the other direction tried with all the costs attendant to using an emergency procedure.

Naturally, arrangements will have to be made for bypassing the normal sewerage flow for the period of time necessary to accomplish the sliplining. Furthermore, building service lines must be temporarily taken out of service until sliplining is completed. In this regard, a short period of time is required to allow initial conformation or expansion to the original dimensions of the liner pipe. It is then and only then that the individual service laterals must be dug up, cut, retapped into the new slipline within the sewer, and reconnected for service. Sliplining does not provide a way in the present state-of-the-art for reconnection of the building sewers from inside the liner. The service laterals are approached as spot repairs that are excavated from the outside.

Once the liner pull is completed and the initial reconformation to original dimensions has taken place, the liner pipe must be cut at the manhole and the annular space between sewer and slipline must be sealed. This prevents extraneous flows entering the old sewer and infiltrating the new slipline at the manhole. In cases where the annular space is larger, consideration should be given to filling the space with grout to 1) prevent transportation of infiltration and inflow, 2) reduce the possibility of liner movement, and 3) provide increased structural support to the deteriorated sewer.

The sealing of the liner at the manholes is a specialty job. The cost of the seal plus the manpower necessary to perform that operation should be included in the cost. Consideration should also be given to sealing the space between the slipline and service laterals prior to reconnection.

Finally, the insertion pit must be refilled and must be restored to pre-existing conditions. This includes the repair or rebuilding of the manhole where insertion was made. Also, the manhole used for winching may need repairs. All these extraneous costs should be accounted for in the estimating process.

The cost of rehabilitating sewers by sliplining can vary greatly due to the several factors discussed. These factors are concisely summarized in the following Table No. 6.

Each of these factors, independently or in combination, can have a major impact on the overall cost of a lining project. A thorough understanding of each of these factors on an individual project basis is required before a realistic cost estimate can be made. Table 7 is presented as an "Estimating Guide." It identifies many of the cost elements that can be segregated for cost determination purposes by sequence of task.

Each lining project is sufficiently different in its complexities, combination of difficulty factors, and variables to make the presentation of any general total cost information impossible. The intent of this section is to provide the reader with a general understanding of the various factors that may affect the cost of a project and the elements that must be considered when developing a cost estimate.

TABLE 6.

FACTORS AFFECTING SLIPLINING COSTS

- Mobilization distance
- Access to the site of work and security
- Storage area at the site for pipe materials
- Storage area at the site for excavated materials
- Extent of sewer cleaning required
- The technique to "prove" or preinspect the sewer line
- Availability and cost of labor
- Availability of electrical power for fusing
- Size of liner pipe to be handled
- Length and location of sewer to be lined
- Size and condition of pipe to be lined
- Liner pipe wall thickness required
- Number of service connections to be made
- Ground water elevation and pumping requirements
- Excavation and earth stabilization requirements
- Grade and direction change of the sewer to be lined
- Depth of flow in the sewer line and by passing requirements
- Lining costs
- Pipe transportation requirements
- Type of manhole "seals" needed
- Annular grouting requirements
- Type of restoration required

TABLE 7.

ESTIMATING GUIDE (COST ELEMENTS)

A. PREPARATION

1. Sewer Line Cleaning
2. TV Inspection
3. "Proving" of Sewer Line

B. COST OF PIPE

1. Diameter of Existing Sewer
2. Diameter of Liner Pipe
3. Depth of Sewer Line
4. Wall Thickness and Strength Required
5. Length of Pipe Required
6. Cost Per lb (kg) of Liner
7. Weight Required
8. Freight to the Site

C. INSERTION PITS

1. Depth of Pit
2. Equipment Required
3. Crew Size Required
4. Crew Cost
5. Time Required
6. Special Conditions
   a) Shoring Required
   b) Dewatering Required
7. Cement for Curing Liner Pit
8. Paving Required
9. Manhole Repairs

D. WELDING PIPE

1. Crew Size Required
2. Crew Rate
3. Number of Welds Per Day
4. Equipment Required - Handling and Fusion
5. Power Requirements

E. INSTALLING PIPE

1. Winch Equipment Required
2. Pipe Handling Equipment Required
3. Guide Pulleys Required
4. Cable

F. OTHER CONSIDERATIONS

1. Sewage Bypassing Requirements
2. Dewatering Requirements
3. Annular Grouting Requirements

G. CONNECTING BUILDING SEWERS

1. Type of Connection to be Made
2. Depth of Connection
3. Crew Size Required
4. Crew Rate
5. Number of Connections Made Per Day
6. Equipment Required
7. Materials Required
8. Cost of Materials

H. SEALING OFF AT MANHOLES

1. Number of Manholes to Seal

2. Type of Seal Required

3. Cost of Seals

4. Number of Seals Made Per Day

5. Crew Size Required

6. Crew Rate

I. TRANSPORTATION

1. Mobilization

2. Demobilization

3. Freight on Materials

Inversion Lining

This technique as with other rehabilitation methods requires consideration of the common factors affecting the economics of the operations which were previously described. Inversion lining also requires that the sewer line be clean, internally inspected, and "proved." Proving the sewer for inversion lining is not as critical as proving the line for sliplining since the inversion liner is somewhat more flexible than a slipline. It is capable of negotiating a wide range of pipe alignments and deficiencies. The previous discussion of sliplining material costing is very similar to the approach to costing of materials for inversion lining with one notable exception, the inversion lining requires a thermal reaction chemical saturating the felt lining material used in the process. The common truth is that as the required diameter and thickness of the liner material is increased, the cost of necessary materials and chemicals also increases. One cost advantage of inversion lining over sliplining is the avoidance of insertion pits.

The technique used in inversion lining is relatively simple. The liner is usually inserted into the sewer main via a standard type manhole from the ground surface. There is the requirement, however, of a scaffold structure immediately above the ground to allow liner to pass smoothly into the manhole and on into the sewer. Water, an important part of the procedure, is introduced to carry the liner into the sewer. The major difference in transportation and preparation costs for inversion lining as compared to sliplining costs is that the thermal plastic resin used in the inversion method is heat sensitive. The felt liner is prepared at a factory and shipped to the rehabilitation site location. Prior to the inversion or introduction of the liner into the sewer, the liner is saturated with the thermal plastic resin normally within 24-hours of use and is then placed in a refrigerated vehicle to prevent the onset of a setting reaction. This process, depending upon the location of the preparation plant in relation to the job site and

weather, can increase the cost of inversion lining significantly because of the need for refrigerated transportation. The inversion liner treated with plastic resin is essentially flowed through the existing sewer to be rehabilitated using the force of water within the inversion tube. It is essential that the job site has the capability of producing and delivering hot water to be introduced into the inversion liner. This accelerates the reaction and causes the thermal plastic resin to set against the existing sewer pipe. Estimates of the cost of this technique must allowed for available sources and disposal points of water and capability of bypassing sewage from street sewers as well as temporarily halting discharge from service laterals.

The cost factors to be considered after inversion takes place are the time and materials necessary to seal the inversion liner at the manholes and the number of service lines that need to be reinstalled on the main line. The process of reconnection of services is accomplished by positioning a cutter adjacent to each building service line inside the main line and by remote control and TV observation plus cutting out the solidified resin material blocking the service laterals. Since the process is remote controlled, an operator may have to position the internal cutter a number of times to determine the exact position of the connector. It is not always evident where the connection is made. The average time for the cutting operation per lateral is about 15 to 20 minutes. As improved techniques are devised, cost of this operation should decrease.

There is no need to grout an annular space since the set resin conforms to the inside surface of the existing sewer. Two types of resin may be used. If an epoxy resin is used, the line must be clean and kept that way or the resin will not adhere well. On the other hand, if a vinyl resin is used, absolute cleanliness is not essential since there is no actual bond created between the liner and the inside of the pipe.

At the present time, inversion lining is a patented process and one which is totally sole source. Therefore, the estimator should be alert to the possibility of price fluctuations of material and equipment as well as an absence of competitive bidding. The inversion lining process presently has been franchised to single source representatives in various areas of the country. Those areas do not overlap and the franchise does not allow the dealer to operate outside of a specific sales territory, thereby creating a single source negotiation type of pricing schedule. It is pointless therefore, to summarize the factors affecting inversion lining costs when you must defer to quotations from francished operations. Typical costs for this type of rehabilitation have been reported (on the East Coast) to be in the range of $50 to $60 per ft for pipe 10 in. (0.25 m) in diameter. The reported costs include line evaluation and preparation before the inversion lining process.

There are additional considerations to a complete rehabilitation project which should not be overlooked. They are sealing infiltration into manholes and probably the most difficult of all, sealing leaking building service laterals.

Manhole Rehabilitation

Manhole rehabilitation costs must be approached from two distinctly different points of view, 1) rehabilitation from infiltration, and 2) rehabilitation from inflow.

Inflow can be estimated by evaluating the elimination of surface rain water entering the manhold cover area and direct drainage connections to the manhole. Costs attendant to this condition are relatively low and inexpensive methods can be employed to eliminate inflow. Reducing this important fraction of the extraneous flows to the sewer can occur during and immediately after rainy periods.

Infiltration on the other hand is somewhat more costly and difficult to correct.

In that regard manhole rehabilitation cost estimates require an understanding and evaluation of numerous interrelated factors. These include type of manhole construction; type, cause, and extent of failure; depth of manhole; type of soil surrounding the manhole; manhole location; the rehabilitation techniques selected; rehabilitation material selected; and other factors. A list of available manhole rehabilitation techniques is provided.

Rehabilitation Techniques:

Internal Cement Grouting by Pressure Injection

Internal Chemical Sealant Grouting by Pressure Injection

External Chemical Sealant Grouting by Soil Injection

External Cement Grouting by Soil Injection

Internal Epoxy Mortar Resurfacing

Internal Cement Mortar Resurfacing or Guniting

Mortar Joint Replacement by Pressure Injection

"External Drop" Sealing

Resetting and Resealing of Manhole Frames

Replacement of Manhole

Each of the above techniques may be utilized separately or combined in various manners depending on manhole condition and the extent, type, and nature of rehabilitation required. The obvious difficulty is in determining which technique or combination of techniques will be most successful in a particular circumstance. The selection is generally dictated by type of manhole construction in conjunction with the nature of the physical failure involved.

Service Lateral Rehabilitation

It is recognized that a substantial fraction of infiltration and in some cases, inflow, can be traced to house connections (building service laterals). Some of the extraneous flow can be observed (at time by TV inspection) to come from the vicinity of a connection to the street sewer. Whether or not the observed flow originates from the point of connection or further up the service line is often unclear. The rehabilitation barrier is the property line.

Costs of service line repairs to date have been relatively expensive due to inaccessibility because of property lines and the incumbent implications. Proprietary methods have been or are in the process of being developed for repairing connections as well as using a chemical grouting method a short distance up the service line. Other methods have included spot repair using excavation methods. The essential problem still remains; repair of relatively shallow house connections (service laterals) on developed and private property. The most inexpensive method would be investigation and repair from the house basement to the street, but by whom, and at whose cost. A recent approach to this problem (on the West Coast) has promise if universally adopted; that would be to make the houseowner responsible for his drain by providing a certification of inspection and rehabilitation of a service line each time a property changes hand. Guaranteed in this manner, poorly installed service lines or lines damaged by roots must be examined and repaired prior to transfer of title. Whether or not this approach becomes popular must await resolution and widespread adoption by governmental agencies.

CHAPTER 6

LONG-TERM REHABILITATION PROGRAM

Any rehabilitation program designed to upgrade sewer systems involves time, personnel and material. The final success or failure of a rehabilitation program depends on materials used, workmanship and maintenance of the sewers once they have been renovated. Accordingly, the administrator of the system should assure adequate inspection during rehabilitation efforts and provide for routine inspection and repairs of the system, that is, a preventive maintenance program.

INSPECTION

"Cataloging" is the first step in the inspection process. It involves taking an inventory of manholes, determining invert elevations, and mapping the direction of flow together with the number of inlets and outlets. If the agency has had a Sewer System Evaluation Study (SSES), most of the initial mapping will be available. Once the known manholes are logged, dye or smoke testing will show the flow routes in the system. When the dye disappears or when smoke appears unexpectedly, investigators can be certain that an unknown manhole or other diversion structure is diverting the flow; they can also estimate where overflows exist in the system. If overflow structures exist, it is possible that they affect inflow.

Next comes the inspection phase. The usual procedure is to insert a remote control TV camera into the sewer line and then to log the conditions observed.

To insert the camera, technicians allow a float with a light line attached to it to float from an upstream manhole down to the next manhole on the run. A cable winch is set over the lower manhole, and the line is connected to a cable. After drawing the cable through the sewer, it is fastened to a winch. The front end of the TV camera is attached to the free end of the cable and a second cable to the rear. A second cable, along with the TV transmission lines, is fastened to a second winch in the survey van. The second winch has a built-in footage counter which is synchronized with the camera's entry into the upstream end of the sewer line. Filming is done in the downstream direction to prevent the flow from fouling the camera lens. If the flow is excessive, the line must be plugged and diverted during the investigation. Using two winches to move the camera back and forth, the operator can locate problems in the line. By keeping a log of observed conditions, the process of decay can be evaluated and recommendations as to repairs required can be made.

For inspection purposes, the system should be separated into such units as drainage areas and city sections. If the inspection team works a specific area, it will be easier to keep track of progress and to ensure that all the lines are inspected regularly.

MAINTENANCE

Maintenance is as important as inspection for an uncorrected problem can lead to the rapid deterioration of other parts of the system. Maintenance consists not only of repairing the deteriorated sections, but also of cleaning the lines to allow free flow. Cleaning is necessary because the lines are seldom constructed on an even grade: slight changes in grade can cause solids to build up in eddies. Along with the solids found naturally in the flow, any number of articles find their way into the sewer line through manholes, catch basins, laterals, and cross connections. These articles range from small stones and grass to auto parts and building materials and they can cause stoppage which not only inconveniences those served, but can cause exfiltration to discharge to the sewer backfill material. At some point in the process a cave-in may occur which may in turn collapse the pipe.

Tree roots cause additional problems. Roots are drawn to moisture which the sewer system provides in abundance. Where the ground water table is well below the sewer system, the sewer is even more threatened.

One of the most widely used methods for protecting sewers from root damage is augoring. Here the root system is cut off with a rotating blade inserted in the line. Since roots grow from their tips, augering is only a temporary solution: the roots begin to grow again at each cut; the cuts are larger in area than the previous tips, and so the roots grow back even larger and stronger.

Recently, several methods have been devised to stunt root growth without killing the vegetation above ground. Two methods currently employed are flooding and foaming the sewer line with a special herbicide. Both methods require the sewer line to be filled with herbicide. Foaming is especially helpful for lines with low flows because it does not require the complete relocation or blocking of flows.

Another technique presently being employed is the mixing of herbicide with sealing grout during rehabilitation of the line. This not only retards root growth, but also seals minor cracks in the sewer line, thereby reducing the amount of infiltration.

CHAPTER 7

LONG-TERM FLOW MONITORING

The success of rehabilitation projects depends on the decrease of infiltration/inflow in the test section. By conducting prerehabilitation testing during the rainy season and postrehabilitation testing during the dry season, a substantial decrease in infiltration flow can be effected. Monitoring under these conditions, however, is worthless. The real test comes from long-term monitoring occurring over several wet and dry seasons; results can then be averaged over a reasonable period of time.

Testing should take several factors into account: prior moisture conditions, flow versus rainfall, flow versus intensity, flow versus duration, and existing conditions.

Upon completion of the rehabilitation project, inspectors should re-evaluate the project area. The evaluation should include an analysis of the extent of the rehabilitation project. Did financial or other constraints limit the work or was there an effort to remove all identified I/I? Were house laterals a part of the rehabilitation program? Were manholes and other structures rehabilitated? If the project area has been made sound, the presence of I/I will indicate either overlooked points of entry, failure of rehabilitation, new sources of I/I, or tranference of I/I from areas outside the project.

The next task, in comparing pre-and postrehabilitation performance, is to evaluate moisture conditions in the soil, at the start of a measured rainfall. If the area to be measured has just undergone a long hot dry spell, the ground may have been baked sufficiently so that most of the initial rainfall runs off and does not penetrate to the sewer line. If the ground is dry but not baked, there will be a considerable delay between the rainfall and a noticeable rise in flow through the sewer line. When the rain has stopped, the flow increase should continue as the ground water level recedes. If the ground is saturated at the time of the rainfall, the flow in the sewer line should continue at a high level and then decrease after it stops raining. Soil conditions at the time that the original estimate of I/I balances were made should also be considered for comparison purposes.

The intensity, duration, and timing of rainfall events are extremely important as to their potential impact on I/I flows. When one rainfall event occurs soon after another, the soil may already be completely saturated; thus, there is almost total run off of the second rainfall, regardless of intensity or duration. When the second rainfall occurs substantially later, the soil has a chance to return to normal and to accept additional rain.

If the soil has returned to normal, two more points must be considered: rainfall intensity and duration. With a normal soil, that is, ground water level at an elevation standard for the area, a light rain of short

duration will create a flow condition for which a hydrograph of the sanitary sewer flow closely approximates the rainfall histogram. The flow will, however, lag behind the rain event because of the time necessary for the water to percolate through the soil and be intercepted by the sewer line. Discounting base line flow, the sewer hydrograph should be less than the rainfall histogram because only some of the rain hitting the ground is actually collected by the sewer line; the rest remains within the soil.

Light rainfall of long duration will also produce a sewer line hydrograph which will lag behind the rainfall histogram. Discounting the base line flow, the sewer hydrograph will be less than the rainfall histogram by the amount of surface runoff.

Heavy rainfall of short duration will have little effect on flow in the sewer because most of the water that reaches the ground will run off, since it has no time to soak in.

Heavy rainfall of long duration will have a greater impact on the sanitary line.

PRE - POST COMPARISON

Fair evaluation of a rehabilitation program demands that inspectors compare conditions existing before and after rehabilitation. Because no two rainfalls have exactly the same characteristics, it is extremely difficult to correlate prerehabilitation and postrehabilitation flows; only through long-term monitoring can the flows be averaged to the point where significant conclusions can be drawn. While agencies like to evaluate projects immediately, inspectors can only give educated guesses until their data is complete.

MONITORING AFTER SANITARY SEWER REHABILITATION

The primary objective of long-term flow monitoring is to measure sanitary system performance against predicted performance, under a defined set of circumstances. This will determine the effectiveness of rehabilitation and act as a "flag" indicating when additional maintenance work is required.

Long-term flow monitoring consists of the development, installation, and operation of a systemwide network following completion of rehabilitation. USEPA now requires "after-action" flow monitoring of the system to "certify the I/I conditions in the sewer system at the end of the first year of operations..."

Specific benefits to be derived from long-term flow monitoring include:

1. Allows the continuous evaluation of I/I conditions.

2. Provides a basis for implementing additional I/I removal, as needed.

3. Provides a constant check on system deterioration, and thus avoids a large "one time" expenditure to update the system.

4. Allows pricing of a system's requirements throughout its life.

5. Identifies areas which are "top priority" for future maintenance.

6. Help to determine if a project has met I/I removal standards.

Long-term flow monitoring involves three phases: preparation of locations, purchase and installation of equipment, and evaluation of the project before and after completion. The first two phases are discussed below:

FLOW MONITORING LOCATION SELECTION

The first step in a long-term flow monitoring program is to select key manholes. Key manholes (KMH) are those manholes selected for installation of a flow meter; manholes with drop services, rough troughs, significant sludge deposits, or sewerage buildup are not suitable. Engineers should also check sewer conditions upstream and downstream from a potential key manhole. This is important for future reference if upstream and downstream lines require calibration. Key manholes located immediately upstream from a highly fluctuating level in a pump wet well will yield poor results. Key manholes immediately downstream from a lift station or force main will also yield poor results. This is also true of key manholes immediately downstream from a lift station or force main because of pump cycling.

Once a key manhole location has been selected, location and the diameter of the line in which the meter is to be mounted should be recorded.

FLOW MONITORING

After selecting key manholes, monitoring equipment must be selected and installed. A variety of long-term monitoring equipment is currently available. Equipment can be as simple as a depth recording meter with

on-site data retrieval or as sophisticated as a meter measuring both flow depth and velocity, with telemetric tie-in to a central computer which analyzes, sorts, and stores flow data.

Flow monitoring should coincide with the operation of a nearby continuously-recording rain gauge. In this manner, engineers can correlate sewerage flows and precipitation data. The "tipping bucket" rain gauge, which is generally used, should be mounted in an area free from buildings and trees-and if possible, at the wastewater treatment plant, city sewer, water department, or some other readily accessible location. Before starting the monitoring period, engineers should check the rain gauge for calibration.

For some installations, level sensing flow meters may be adequate. Where possible, flumes or weirs can serve as primary flow measuring devices. In pump stations with constant speed pumps, an event recorder can monitor flow. Occasionally, such meters will be inadequate and other kinds of meters will have to be used.

Initially, meters should be serviced at least once a week and after major rainfalls. After engineers have verified that meters are operating properly, semiweekly or monthly maintenance may be all that is necessary. Recorded meter depth should be checked against the measured depth and adjusted accordingly. Velocity readings should also be taken to provide calibration data. There should be a suitable site for the storage of batteries and spare meters, and for battery charge.

For those gravity flow monitoring locations without a primary measuring device, calibration is required to correlate flow rate and liquid depth. This is best performed during an infiltration and inflow period when fluctuations in flow are greatest.

Engineers should establish at least four calibration points covering a wide range of depths, and should conduct both instantaneous calibration and dye-travel calibration. The calibration done at the meter location will establish the average velocity. The dye is placed either in the manhole upstream from the key manhole or in the key manhole itself. By using a stopwatch, the time that is required for the dye to reach the downstream manhole can be estimated. Depth of flow measurement of the key manhole at the point where the float will measure must be made, noting any deposition. Instantaneous velocity probes may be used at the point where flow was measured. But readings decrease in accuracy with low depth of flow. To determine an average velocity using the time of dye travel, the distance between manholes must be measured with a tape or rollotape wheel. The invert elevation of the sewer must also be determined.

After a satisfactory calibration curve for each location is established, the depth data can be converted. When contractors are involved in digitizing flow results, engineers should maintain a log of charts and resulting printouts, together with mailing dates, dates they received printouts, and the chart numbers for both the printouts and the charts.

All digitized data must be analyzed promptly to assure that it is satisfactory.

Engineers can calibrate pump stations by the "fill and draw" method or by a sonic meter mounted on the force main; they can also take depth and velocity readings to measure peak discharge at the end of the force main.

Information on servicing and calibration should be kept in a log book. Each monitoring location should also be recorded. Exact diagrams or drawings of each location should be made, noting the kind of meter, date of installation, and any other distinguishing information.

When servicing a location, a record of problems encountered such as added deposition in trough, debris on a float, recorder malfunction, or battery failure, etc., should be made. If data appears to be missing or conditions indicate that data may be unreliable, such observations also should be recorded in the log book as well as on the strip chart, if available.

Primary Measuring Devices

A precalibrated primary measuring device such as a weir or flume can simplify meter installation and calibration. Meters which measure both flow depth and flow velocity do not require a primary device.

Weirs and flumes each offer advantages and disadvantages. A weir is the simplest device for measuring flow in open channels. It is cheap, relatively easy to install, and quite accurate when used properly. However, a weir normally operates with a rather significant head loss, and variations in the approach velocity of flow can affect its accuracy. Also, weirs require periodic cleaning to prevent sediment or solids buildup on its upstream side, for this, too, reduces accuracy.

A flume tends to be self-cleansing since the flow through it has an increased velocity and there is no actual "dam" across the channel. Then too, flumes operate with a much smaller head loss than a weir, an important factor in cases where the available head is limited. An added benefit is that varying approach velocities do not affect a flume as much as they do a weir.

Equipment Selection

Equipment selection involves consideration of initial cost, maintenance cost, accuracy, system reliability, and ease of data acquisition and reduction. To be effective, long-term flow monitoring systems require low maintenance and easy data acquisition and reduction. Equipment with telemetry and computer data retrieval and reduction is therefore recommended; failing that, equipment should at least have a computer summary of stored data, with on-site retrieval.

Several manufacturers offer sophisticated flow monitoring equipment:

although the initial cost is more than that of simple short-term monitoring systems, equipment with computer telemetry and/or data reduction capabilities accomplishes more, requires less maintenance, and is therefore more economical.

CHAPTER 8

REGIONAL SITE VISITS

In the latter part of 1982, and early in 1983, the staff of APWA held ten meetings with interested federal, state, local agencies, and consultants regarding control of infiltration and inflow into sanitary sewers. While all of the regions reported problems with inflow and infiltration into their sanitary lines, some of those problems crossed regional boundaries. The staff found that there were many divergent regional differences.

120 GPCD AS GUIDELINE

In general, all of the regions agreed that instituting a single all-encompassing empirical value for excessive flow in a sewer system is not the preferred way to attack the problem. The consensus was that while an empirical number may well be a good starting point, the local agency should have the opportunity to evaluate its system to determine if the final evaluation number would be higher or lower than 120 GPCD (454), based on local operating conditions. The evaluation should take into account such factors as population density, climatic condition, age of the system, kind of population, and certain other geographical considerations which influence the groundwater table.

HOUSE LATERAL CONSTRUCTION PROBLEMS

A major source of inflow discussed at most site visits resulted from house laterals constructed at a different time than the main sewer line and to less rigorous inspection standards. Participating agencies indicated that generally the main sewer line which lays in the right-of-way and is the main transport vehicle for sewerage was constructed either with agency forces or contracted out to private construction firms and inspected by agency forces. Either way, this resulted in a product which generally was constructed well enough to meet the standard critera for maintaining the long-term integrity of the sewer line.

Service laterals, on the other hand, are generally laid at the time a building is constructed. This could be years after the installation of the sewer main. Also, this work is generally done by a plumbing contractor or general building contractor. Usually, this work has had little inspection or testing and the sewer line is often laid on a poorly prepared subgrade with little or no attention to proper sealing of joints. Backfill of the sewer trench is often accomplished with only readily available materials.

Because of these factors, the sewer line generally settles over time, the joints separate, a rock in the fill may penetrate the sewer line, or the alignment of the sewer line itself may shift and shear the pipe. All of these situations result in significant defects which will allow infiltration.

To further complicate the problem, it is a general construction practice to lay the building sewer on a minimum grade from the building line to the property line. At the property line, the lateral sewer grade is increased significantly to intercept the sanitary sewer below. This procedure is followed because it is less costly to the contractor laying the line, since most of the pipe run will be in a shallow trench, as compared to the last 15 to 20 ft. run (4.6 - 6.1 m) of the service lateral. Because of the steep grade and the other factors which have been noted, a significant amount of stress is placed at the junction of the building sewer and the main sewer line. If the contractor has been diligent, he will intercept the sewer line at the location where a wye or tee has been placed for access into the main sewer line. If not, a standard is to stab a section of building sewer line into the side of the main sewer and patch the area with mortar. Theoretically this seals that location from infiltration or inflow. Over time, the stress at that point generally results in the connection opening up and allowing a significant amount of infiltration into the main sewer. Because of the current design of sewer rehabilitation machinery, such a joint is almost impossible to seal.

HOUSE LATERAL CONTRIBUTIONS

While there is almost no concrete evidence to support the participants' feeling, all intuitively indicated that apparently the house lateral or service line is a major contributor to the I/I flow for reason cited. One rehabilitation project in Washington State was staged and the I/I reductions achieved as a result during the project seemed to bear that out. In a second project currently underway, the Washington Suburban Sanitary Commission is studying both the effects of groundwater migration and the effect of service laterals in I/I. The work accomplished to date with a sewer sock appears to reinforce the idea that service laterals are a major contributor to I/I. Finally, several areas in EPA Region 1, especially in New England have begun demonstration projects to place underdrain and clay barriers adjacent to sanitary sewer lines in an effort to reduce the infiltration and inflow into the sanitary sewers.

HOUSE LATERAL REHABILITATION TECHNIQUES

Agencies are currently using two techniques to try to solve such problems. One is to position the packer over the building lateral and fill the lateral with grout. Once the grout is set up, an auger is sent down the house lateral to ream the inside of the service lateral and allow usage again.

The second technique being used in Washington State and by the Washington Suburban Sanitary Commission is what is referred to as a "sewer sock." This is a specially-adapted grouter which has a 6 ft. (1.8 m) long sock that can be projected into the house lateral for 6 ft. (1.8 m). A doughnut is

then inflated at the end of the grouter, and grout is pumped along the outside of the sock, sealing the house lateral. Once the grout has set up, the sock is deflated, pulled back out of the house lateral, eliminating the need to remount the lateral itself. Several problems are yet to be worked out with this particular technique: One is extensive wear and tear on the sock and the second is that it is almost impossible to project the sock up into laterals entering the sewer directly from the crown of the sewer main.

SINGLE POINT VS. MULTI POINT MONITORING

Considerable discussion was held at the site meeting regarding the requirement in CG 82 regarding single-point monitoring of the system to determine excessive I/I. Only in New England, where towns are small, did participants indicate that single point monitoring at the plant would be adequate. This was supported by the fact that, with a few exceptions, most New England towns were very small and therefore, the sanitary collection systems were very small too. Thus, they could approximate a single sub area with a monitor at the key manhole. Representatives from all other regions expressed some displeasure at the prospect of plant monitoring. With few exceptions, the agencies have existing monitoring points so that a reasonable division of the system could be accomplished. They indicated that one reason plant monitoring might be inadequate is that, with few exceptions, the agencies have existing bypass structures; that is, a facility operating only during high flow periods which will eject from the system those flows greater than the system is capable of transporting. Such a facility generally would be quite prevalent in an older system found normally in the East, and in some cases, in the Northwest. These facilities are found in these systems because, during their early development, prior to institution of treatment plants, combined sewers were built and the flow discharged directly into a receiving water.

With the advent of treatment plants for regional areas and individual municipalities, a series of intercepter lines have been constructed which have diverted the flow from individual collector lines prior to their discharging to the receiving water.

In many cases, the intercepter was constructed to accommodate maximum sanitary sewer flows regardless of stormwater surcharging. The overflow was built to take care of those situations immediately following rain events which tremendously surcharged the system. The overflow would relieve the backwater condition and thereby reduce the amount of basement flooding in the system caused by the backup.

ILLEGAL CONNECTIONS

A similar condition of inflow occurs in the East and other older sections. In many cases, where a combined sewer was constructed, the street drainage system was tied into the sewer as well as downspouts from the houses, sump pumps in basements, and foundation drains. Often those agencies responsible for the sanitary sewers have indicated existing inflow points generally are cost effective to remove, with the exception of foundation drains. Because foundation drains are almost as deep as the sanitary sewer as a rule, storm sewers would not be located in places where the foundation drain could be tapped into it. Without a sump pump there is nowhere the water which collects in the foundation drain can be put other than in the sanitary sewer where it currently is collected. For these reasons, these agencies say it is impractical , for the most part, to remove the foundation drains. Conversely, while they have found that downspouts, sumps, area drains, and other similar inflow points can be removed economically, they are extremely difficult to maintain when disconnected. This requires constant surveillance of systems and continual removal of the inflow points as they are reconnected.

Generally, a property owner does not appreciate the downspout running stormwater into his yard and forming a puddle which may take from five minutes to several hours to drain back into the soil; thus, creating an unpleasant soft soil condition with which he must contend. It is, therefore, much easier for the owner to reconnect the downspouts, sump pumps, and area drains to allow for quick disposal of the water from his property. Several municipalities in a number of the regions have considered suggesting a remedy of placing a surcharge on the sewer fee of property owners with "illegal sources" connected to the sanitary system; the surcharge would be adequate to pay for the cost of additional transportation and treatment. Furthermore, that surcharge may in fact be levied for varying amounts at various times of the year depending upon the natural ground condition and maximum points of peak inflow which the system experiences during the year.

CROSS CONNECTION

While a demonstration project for installation of underdrains and clay barriers to prevent groundwater migration and to lower the groundwater table around sanitary lines has been discussed, several regions indicated that many underground utilities lie adjacent to one another within the street right-of-way. Sanitary sewers, potable water lines, and storm sewers in particular often parallel each other and, in some cases, even run in the same excavated trench.

Investigation of parallel storm and sanitary systems has shown in certain cases, migration from the storm sewer when surcharged to the sanitary sewer through leaking joints. In other cases, they have found potable water in the sanitary sewer finding its way into the sanitary sewer because of leaks in the pressurized water system.

In the northern areas, a parallel to leaking water mains occurs during the winter. Because of the prolonged cold experienced in those areas, property owners will leave a trickle of water running to prevent their potable water lines from freezing. This results obviously in raising the domestic sewerage component of the total flow in the sanitary sewer line during the winter. Parenthetically, this is another reason for not using a hard and fast 120 GPCD (454) amount to determine excessive I/I in a system.

MANHOLE INFLOW

In the same northern areas, a phenomenon known as "frostheave" creates havoc on manholes in the winter. The upward movement of the ground has been known to completely separate manhole frames and lids from the riser of the manhole by some 2 to 3 in. (5.1 to 7.6 cm). This breaks the mortar seal at that particular location. If water is found running along the subgrade, which is especially common under concrete streets, the broken seal between the frame and the corbel is a perfect entry place for the inflow.

MIGRATION OF GROUNDWATER

One of the major discussions for which there is only a small smount of hard data to complement the intuition of those agencies in the area, is the phenomenon of groundwater migration. Here again, the Washington Suburban Sanitary Commission currently has a research project underway to investigate this phenomenon. But it is the intuition of those who work with the sanitary system that when a visible inflow point in the sewer is fixed with no regard to the condition of the line upstream and downstream, the hydraulic head is increased at the point of repair. This forces the groundwater out through smaller failures in the pipe, which did not leak prior to the original repair. Therefore, while there is a 100 percent reduction of infiltration from the point of repair, the total reduction of infiltration in that particular reach is infinitesimal since the increased hydraulic head is now forcing the water through many smaller holes. Through the use of trace materials, groundwater gauges, and flow monitoring in the sanitary sewer lines, the WSSC hopes to be able to define empirically the effect of groundwater migration on a sanitary line after rehabilitation. They hope to make a better determination of the extensiveness of rehabilitation required to effectively reduce the amount of infiltration and inflow into a reach of line.

COST EFFECTIVE I/I REMOVAL

Finally, the agencies felt that removal of inflow is cost effective and should be done positively to reduce transport and treat costs. If a rehabilitation is planned for a sewer network, they feel that contributors of major inflow should be removed first so that the ground water migration effect can be maximized to pinpoint as many as possible

of the smaller leaking joints. In this way, the rehabilitation evaluation will not just identify the major contributors, but will give a fair representation of the actual condition of the line prior to rehabilitation. With full knowledge of the condition, perhaps a better rehabilitation project can be instituted which will show a much more dramatic reduction in I/I than past infiltration/inflow projects have shown.

While the agencies acknowledged that they need to reduce inflow and infiltration in their sanitary sewer systems, they recognize that realistically the priority for I/I work is very low. As long as downspouts and/or sump pumps and area drains are allowed to exist in the sanitary system because local agencies do not have funding adequate for this kind of work, I/I will continue to be a problem in the sanitary sewer systems. At present, all of the local agency's money is being spent to maintain a system which is rapidly deteriorating and in allowing the system to transport the total flow from the points of input to the treatment plant, no matter how much I/I it captures along the way.

NEW DEVELOPMENT STANDARDS

Many participants in the site visits indicated that better methods of lowering groundwater tables should be investigated. They believe that, in many areas the easily developed properties have already been utilized and development must now occur in areas more prone to problems with respect to construction techniques and drainage, to mention a few. Since developers must now utilize property which does not drain well, both sanitary and storm sewer systems will more often be subjected to high water tables than was true of those constructed previously. While this makes no difference in storm sewer, the sanitary sewer must be able to withstand the increased potential for infiltration and inflow. As aging occurs in the sewer lines, defects will begin to appear and infiltration will become evident.

IMPROVE BUILDING LATERAL ACCESS

With the advent of the 2 in. (5.1 cm) self-propelled TV cameras, house laterals can now be checked readily to determine their condition. In many areas of the Northwest, it is required that the builder or property owner provide an access point to the house lateral somewhere outside the structure. This access point is normally a clean out.

This provides the utility with the ability to enter the lateral with investigation equipment, and where necessary rehabilitation equipment, without having to excavate the entire lateral in order to rehabilitate it. In some cases, the utility has actually constructed the clean outs on house laterals where the original construction occurred before the requirement for an exterior access point.

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